INTERIOR VIEW OF 42″ CONDUIT NO. 2 OF THE EAST JERSEY WATER CO., 1896. (Looking down-stream.)

[*Frontispiece.*]

115 EXPERIMENTS

ON THE

CARRYING CAPACITY OF LARGE, RIVETED, METAL CONDUITS,

UP TO SIX FEET PER SECOND OF VELOCITY OF FLOW.

BY

CLEMENS HERSCHEL,

HYDRAULIC ENGINEER,

S.B. (Harvard, 1860); Past Pres. Boston Soc. C. E.;
M. Am. Soc. C. E.; M. Inst. C. E.;
Superintendent and Engineer of the East Jersey Water Co. of New Jersey.

"If we wish accurate knowledge of the area of a sharply bounded field, is it not better to take a steel tape and a first-class modern transit and go out and survey it, making a clean, fresh, first-class job, instead of hunting among the archives and averaging the more or less rough surveys of the past hundred years?"—JOHN R. FREEMAN, M. Am. Soc. C. E. (*Tr. Am. Soc. C. E.*, 1890, **I**, 82).

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PREFACE.

OF the 115 experiments discussed in this little book, 84 are original, and now for the first time published. These are, also, mostly experiments on a class of conduits on which no experiments have yet been printed, so far as the author knows. They are a contribution to knowledge on the subject by the East Jersey Water Company of New Jersey.

This book is also intended to record a remarkable and instructive incident in the development of knowledge concerning the carrying capacity of large riveted conduits. From the day when the carrying capacity of the Rochester, N. Y., conduit was stated then to be 9,292,800 U. S. gallons per 24 hours, in an official report by a public officer, down to the time when a number of gentlemen engaged in an important public enterprise suffered the loss of no inconsiderable sum of money, not to speak of mortification and annoyance, in direct consequence of this most reckless and unfounded statement, nineteen years had elapsed, and the parties representing cause and effect were widely separated, and strangers to each other. Once again had been illustrated the moral law which makes evil produce a chain of evil, and makes the guiltless suffer both for and by the acts of the guilty.

To his principals during the years from 1889, and at the present time, who by their steadfast support have given him the opportunity in a fitting manner to publish this record, and to the many friends in the profession who chose to convey to him avowals of their continued loyalty and good-will during a brief period when to do so was plainly not in the fashion, the thanks and appreciation of the author are here publicly expressed.

CLEMENS HERSCHEL.

2 WALL ST., NEW YORK CITY,
February, 1897.

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"History is Philosophy learned from examples."
—THUCYDIDES (abt. 454 to 396 B.C.).

"It is astonishing how a solemn manner and a noble style will carry unsupported and unfounded statements without dispute for generations."
—HENRY CABOT LODGE,
Scribner's Magazine, 1897, p. 234.

PREVIOUS to 1889 there were no long, rivet-jointed, riveted conduits east of the Mississippi or of the Missouri River, and no doubt very few, if any, elsewhere, the world over. The nearest approach to such, on the Atlantic seaboard, were the short flumes, or trunks, used in the New England States to convey water to turbine-wheels for power purposes, and the 7.5-ft. pipe of wrought iron carrying the waters of the Croton Aqueduct across the High Bridge over the Harlem River. This pipe was built in 1861 by that veteran engineer, Gen. Geo. S. Greene, happily still with us at the age of 96, and his assistant, Mr. W. H. Dearborn. There were also some riveted pipes used to convey natural gas in Pennsylvania, having flange or Converse lock-joints, and a conduit laid in

1876 to supply Rochester, N. Y., with water, which likewise was a riveted tube with flange-joints, or bell-and-spigot lead joints, at short intervals.

In California and on the Pacific coast generally, on the other hand, such continuously riveted conduits had been common for twenty or thirty years then past. The lack of coal and iron in those States made it necessary to import water and other pipes from abroad, or to freight them from the Atlantic seaboard, and this soon led to the adoption of sheet- and plate-iron riveted pipes as a matter of economy in freight-bills. This class of pipes is described in "A Practical Treatise on Hydraulic Mining, etc.," by Aug. J. Bowie, Jr., M. E. (New York, Van Nostrand); in papers by Hamilton Smith, Jr., M. Am. Soc. C. E., in the Tr. Am. Soc. C. E., 1883 and 1884; and in Hamilton Smith's "Hydraulics" (New York, John Wiley and Sons, 1886). These books and papers contain also experiments on the discharge of such pipes, to be discussed in subsequent chapters. At present it need only be said that the largest pipe experimented on, with ordinary velocities of flow, had a diameter of 1.23 ft., while the largest that had been built in California up to 1889 is believed to have been a conduit 3.67 ft. in diameter, built for the Spring Valley Water Company of San Francisco.

Between June 1873 and January 1876 the city of Rochester, N. Y., laid a line partly of 24″, partly of 36″ wrought-iron riveted pipe, partly of 24″ cast-iron pipe. This pipe-line first became known to fame through the Annual Report of the Executive Board of Rochester, N. Y., 1877, containing also the Report of the Chief Engineer of

Water-works to the Executive Board, of January 1, 1877. This is what the report says as to the discharge of this pipe-line: "Aside from the crude records of the gate-keepers at the two reservoirs, and which can have no scientific value, only one careful measurement of the flow from Hemlock Lake into the Storage Reservoir was made by my former able assistant, Mr. L. L. Nichols. This was done by a very accurate observation of the rise of the water-surface in the Storage Reservoir during a period of eight hours; and as the exact dimensions of the basin were all known, the quantity of water delivered through the pipe was then computed, and found to be at the rate of 9,292,800 gallons per day. These figures refer only to the volume contained within the faces of the reservoir banks, and without any allowance whatever for absorption by the latter, which were at the time perfectly new and had never before been subjected to the action of water."

This remained in engineering literature the only experiment claimed to be reliable on the carrying capacity of riveted pipes larger than Darcy's 11¼-inch sheet-iron pipe of 1850, larger than the California pipes gauged by Hamilton Smith, Jr., and so large as 36″ in diameter, until the reading or publication of the paper "On the Hydraulics of the Hemlock Lake Conduit of the Rochester, N. Y., Water-Works," by Geo. W. Rafter, M. Am. Soc. C. E., read Oct. 21, 1891, printed in the Transactions of that society, January 1892; that is, a matter of fifteen years; and it remained thus, it should be noted, without dispute, and without even a suspicion expressed concerning its integrity. Even then, as will be seen presently, suspicion and attack were directed

as late as 1892 against the new-comer, against Mr. Rafter and his supposed heterodoxy, instead of being directed against the old-time pretended gauging and the imposition it had, for so long a period, been practising upon students of hydromechanics and upon civil and hydraulic engineers.

In October 1886 the present writer made a series of experiments on the discharge of a 9-foot trunk, or flume, at Holyoke, Mass., recorded in the Nov. 1887 number of the Tr. Am. Soc. C. E. Unfortunately this flume was only about 153 feet long, that is, only 17 diameters long, and as the results found did not accord with those stated in the Rochester public document of 1877, as derived from "careful measurements" by an "able assistant" who had made "very accurate observation of the rise of the water-surface" in a storage reservoir, due to the discharge of a 36″ conduit some 10 miles long, this circumstance cast great discredit on the applicability for general purposes of these Holyoke results.

This impression was confirmed by the new results not agreeing with those found by Hamilton Smith and by Darcy for riveted conduits, while all the other gaugings that have been named agreed fairly well among themselves. So that the Holyoke results stood alone, unsupported and unconfirmed by a single one of those found from any previous published experiments.

Under the circumstances it is plain that the remarks then made concerning the Holyoke results were entirely justifiable. This is what is said about them in the paper referred to: "I judge from the disagreement of the results above given with those found at other places, but on longer tubes, either that

piezometers do not correctly indicate the *h* of the formula (see Hamilton Smith's 'Hydraulics'), or else that a uniform and non-accelerative régime of the flow of water through the trunk had not become established in the comparatively short length at command for purposes of measurement."

In the fall of 1889 the author came to New York to take charge of the construction of the plant of what subsequently became the East Jersey Water Company; a company organized for the purpose of building primarily water-works of a capacity to supply to Newark 50 million gallons daily (77.4 cubic feet per second). By the contract entered into Sept. 24, 1889, these works had to be completed on May 1, 1892, and in September 1889 it had not yet been definitely decided from what drainage-area the water-supply should be taken, the contract providing that it might be taken from one of three named valleys.

It therefore soon became evident that masonry conduits, and cast-iron pipes as well, were excluded by the terms of the contract. As finally located, it was required that a conduit, to act, in places, under 340 feet head, and not smaller than 48″ in diameter, 21 miles long, should be built in an economical manner in two working seasons. No long 48″ cast-iron pipe conduit had been used under such a head, nor could one be built 21 miles long, in two working seasons. For many reasons cast iron was practically excluded by the requirements of the contract, and the choice of the riveted-steel conduit adopted was thus born of the necessities of the situation.

The consequent works of the East Jersey Water Company have been described by the author in the September 1893

number of the Journal of the New England Water-works Association.* At present we are only concerned with the 48″ riveted-steel conduit, 21 miles long, and a 36″ branch, 5 miles long, forming a part of these works, and other conduits built in 1895 and 1896.

* See also *Engineering News*, June 15, July 6 and 13, 1893; and Foreign Abstracts, Inst. C. E., vol. 114.

CHAPTER II.

COMPUTATION OF A 48″ RIVETED CONDUIT BETWEEN OCT. 1889 AND DEC. 22, 1889.

"Looking back with the cheap wisdom which is supplied by the event, it is not difficult," etc., etc.
LECKY, 1896. *Democracy and Liberty*, Chap. VI

"Tadeln können zwar die Thoren,
Aber klüger handeln nicht."—LANGBEIN, 1788.

(Though the shallow-witted can criticise, they could not have acted more wisely.)

IT has been stated above what were the available data in 1889 from which to compute the carrying capacity of a riveted conduit. The chief of these, because nearest to the size and velocity to be provided for, was the stated and universally accepted Rochester gauging of 1876. And as Mr. Emil Kuichling, M. Am. Soc. C. E., had taken a prominent part in the design, construction, and operation of the Rochester conduit, he was engaged in October 1889 to aid in the design of the riveted conduit, then contemplated.*

What then was the "state of the art" of computing the carrying capacity of a riveted conduit which any two engineers charged with such an undertaking in 1889 had to confront them or to enlighten them?

Darcy's $11\frac{1}{4}''$ plate-iron pipe of 1850—exact construction

* See Note A in the Appendix.

not stated, other than that it was no doubt riveted and had been dipped in asphalt *—gave a discharge greater than if it had been new cast-iron pipe.

Hamilton Smith's riveted pipes all gave discharges uniformly greater than or equal to those given by new cast-iron pipe.

The Rochester 36″ riveted pipe had been officially lauded as having shown a discharge which would indicate a coefficient equal to 134 ± 3%, under conditions which would cause new cast-iron pipe to have a coefficient of about 124. That is, the Rochester riveted 36″ pipe had been officially reported to have a discharge some 8% greater than new cast-iron pipe, other things being equal.

The only published or then known experiments on riveted pipe that had given discordant results were those by the author on the Holyoke 9-foot conduit only 17 diameters in length, that is, similar to a piece of an ordinary ⅝″ service-pipe less than 11 inches long, which for the reasons stated above were not considered reliable for general application.

Working independently, both Mr. Kuichling and the author treated large riveted pipe therefore as of equal carrying capacity with new cast-iron pipes. To do so had been the final result of Hamilton Smith's studies, as laid down in his book "Hydraulics," of 1886, the genesis of which was well known to the present writer, and whose author he had personally known while the book was in press, and then, as since, held in high estimation as a most conscientious experi-

* Presumably this pipe was similar to the sheet-iron and asphalt pipes used by Darcy in Dijon, and described in his book entitled "Les Fontaines Publiques de la ville de Dijon" (Paris, 1856).

menter and hydraulic engineer. To do so had been the practice of a long list of able engineers, here and abroad, who are in print to that effect; and even so late as 1892, as has been stated, prominent engineers in this country still did so.* And it is no attack upon the profession to make this statement, nor to quote the authorities for making it. Nor is it depreciatory of the science or the profession of the civil engineer. Knowledge on such a subject as the computation of the discharge of riveted conduits can progress no faster than the making or the publication of experiments upon such discharges. And when the poison of an erroneous statement has once been instilled into the data on which is founded a branch of human knowledge of this sort, it cannot fail to work incalculable mischief, until every particle of it has again been removed.

Of course there was no time in the fall of 1889 to make new experiments, as actual construction work had to be prosecuted energetically. The "state of the art" had to be taken as it then was, and writers on hydraulic engineering who had given the carrying capacity of riveted pipe any attention, here and in Europe, from 1877 up to October 1890, had been deceived by the officially published pretended gaugings of 1876 of the Rochester conduit. Thus they remained until Mr. Rafter's gaugings were made in July and August 1890, and showed that the Rochester conduit was carrying about $2\frac{1}{4}$ million gallons less than it had been credited with, a rumor of which result was soon spread abroad. It was this rumor that gave rise to the first suspicion that the 1877 report was

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* See Tr. Am. Soc. C. E., 1892, 1, p. 28.

not to be relied on, and this suspicion became evidence, to those who were sufficiently informed to accept it as such, when Mr. Rafter's paper was read in October following.

Between October 1889 and the end of that year, Mr. Kuichling therefore computed the Newark pipe exactly as though it had been a new cast-iron pipe. The formula used was that of Lampe:

$$s = \frac{h}{l} = 0.00039211 \frac{v^{1.802}}{d^{1.25}}.$$

The result was a pipe 47 inches in diameter, on a slope of 11.8 ft. per mile.

This computation the author checked by the use of the table on page 271 of "Hydraulics," of Hamilton Smith, Jr., and Mr. Kuichling's result was changed to a pipe nowhere less than 47¼ inches in diameter, on a slope of 2 per 1000, or 10.56 per mile, which is a trifle more than called for by the Lampe formula; a formula which the Rochester gauging of 1877 was then supposed to have confirmed, established, and even exceeded.

No allowance was made in the computation for deterioration of carrying capacity by the formation of tubercles. This was omitted because it was then supposed that steel pipes would not deteriorate in this way, like cast-iron pipes; or, as stated in Hamilton Smith's "Hydraulics" above quoted, would remain free from rust and tubercles. The author has no recollection of having especially discussed this subject in 1889, or prior to July 1890, or consulted any one about it then, and he accepts professional responsibility for the omission to provide for deterioration of carrying capacity by

slime, spongilla, or other causes in the steel conduit, as has since been shown necessary.

It may be that somewhere there was an engineer who had published reliable gaugings prior to January 1, 1890, that showed or indicated the true discharge of large riveted conduits. If such there was, his publication has not at date of writing been discovered in this latitude. What we do know is that all engineers who wrote upon the discharge of riveted conduits prior to 1890 treated them or found them the same in capacity of discharge as smooth, new pipes.*

This history also shows the dependence of hydraulic science upon the altruistic duty of its practitioners to publish their experiments and discoveries, in order that it may increase and they as a profession may advance in knowledge, and be the better able to cope with the world's needs and work.

Incidentally it also shows the need and prospective utility of hydraulic observatories: something the world has confessedly been sighing for since the days of Galileo. Happily, also, this need is now in process of being removed by several hydraulic testing flumes and observatories recently constructed in the United States by engineering schools.

Before taking up a discussion of the cause of the delusion or deceit under which all these men and the branch of hydraulic engineering now under discussion had been laboring until August 1890, or later, it may be well briefly to state the outcome of the computation considered in this chapter. The conduit described began to deliver water April 26, 1892,

* See Note B in the Appendix.

and the draught upon it was some 20 odd million gallons per day until January 10, 1896. On that date two large municipalities, instead of one, began to draw upon it, and its capacity was then determined to be about 35 million gallons. When new, this capacity had probably been about 43 million gallons; that is, in 4 years it had lost 8 million gallons of capacity. The use of flashboards on the dam raised the discharge to 36 million gallons (coefficient of up-stream end of pipe about 91.5); and a scouring the pipe received from anchor-ice increased this to 37.5 million gallons (coefficient about 98, or 7% increase of coefficient on the first 10,000 or 12,000 ft. in length of the pipe). Experiments upon this conduit will follow in later chapters.

CHAPTER III.

THE ROCHESTER CRIME AGAINST HYDRAULIC ENGINEERING.

"Das eben ist der Fluch der bösen That,
Dass sie fortzeugend immer Böses muss gebären."
—SCHILLER, 1800. *Die Piccolomini* (5, 1).

(Precisely this the curse of evil deed,
That breeding on, it ever evil must produce.)

"Cosmos, Duke of Forence, was wont to say of perfidious friends that 'We read that we ought to forgive our enemies; but we do not read that we ought to forgive our friends.'"
—BACON, 1561–1626. *Apothegms*, No. 206.

THERE has been a singular disposition in certain places to shield and palliate the publication of the pretended $9\frac{1}{4}$-million-gallon gauging at Rochester, N. Y., of 1876. It has gone to the extent of endeavoring to prove, or to cause the impression to prevail, long after it should have been known to be a mere "fake," and down to the present time, that it had been correct when the pipe was new; the explanation being vouchsafed, or intimated, that it had diminished $2\frac{1}{4}$ million gallons, or 25%, in carrying capacity in sixteen years. The assistant engineer who made the gaugings in 1876 has been praised as entirely reliable and unusually able in this especial line, and so the fog has been invoked to settle down upon the subject.

But this will not do in the interests of an advancement of learning or of knowledge. Scientific data must be judged by methods making at least some attempt at scientific precision, and the statements made in the Rochester official report of 1877, concerning the carrying capacity of the Rochester riveted conduit in 1876, must stand their trial in due form before hydraulic engineers.

These were the statements referred to:

' During the construction of the conduit, I stated that its capacity would be about 7,000,000 gallons per day in accordance with my calculations from standard hydraulic formulas; but from some careful measurements which have since been made, it was found that the actual flow was greatly in excess of the amount stated, being in fact about 9,293,000 gallons. As the difference between the actual and calculated flows is here exceedingly marked, I have thought that a brief statement of the original computations, together with a comparison of a number of hydraulic formulas in common use, may perhaps be interesting to our citizens, and particularly to hydraulic engineers. . . .

" It is to be regretted that from want of time a series of reliable and long-continued observations in regard to the actual discharge of our conduit has not yet been made. Aside from the crude records of the gatekeepers at the two reservoirs, and which can have no scientific value, only one careful measurement of the flow from Hemlock Lake into the Storage Reservoir was made by my former able assistant, Mr. L. L. Nichols. This was done by a very accurate observation of the rise of the water-surface in the Storage Reservoir during a period of eight hours; and as the exact dimensions of

the basin were all known, the quantity of water delivered through the pipe was then computed, and found to be at the rate of 9,292,800 gallons per day. These figures refer only to the volume contained within the faces of the reservoir banks, and without any allowance whatever for absorption by the latter, which were at the time perfectly new and had never before been subjected to the action of water. But even if it be assumed that no loss of water occurred, yet the above-mentioned discharge is nevertheless far in excess of the quantity obtained from the hydraulic formulas in common use, as will be seen in the following."

Under date April 6, 1891, Mr. Kuichling, as Chief Engineer of Water-works, reports thus:

"THE ORIGINAL DISCHARGING CAPACITY OF THE CONDUIT.

"The conduit line was practically completed and water from Hemlock Lake was first delivered into Rush Reservoir on January 22, 1876, and into Mt. Hope Reservoir on the day following. Gaugings of the capacity of the conduit were undertaken soon afterwards by the late L. L. Nichols, C.E., who was one of the assistant engineers employed upon the construction of the works, and who had for many years made the subject of theoretical hydraulics a special study. It is greatly to be regretted that Mr. Nichols did not write out a detailed account of the manner in which he made his observations of the discharge of the conduit, and that the only available records of these gaugings are the compactly tabulated figures and memoranda contained in two certain field-books used by him, and in a large private record-book in which he had transcribed various other interesting computations. From these data it is

learned that the discharge of the conduit into Rush Reservoir was measured on four different occasions during the year 1876; and as recent gaugings have shown a flow considerably smaller than what was then obtained by Mr. Nichols, it may be of interest to submit here the original memoranda by Mr. Nichols, supplemented by such other information relating thereto as it has been possible to obtain.

"'On the 27th day of January (1876) the water was passing through the pipe from the lake. At 0 h. 30 m. P.M. (Jan. 27) the water stood 6.40 feet above the bottom of (Rush) Reservoir, at 0 h. 30 m. P.M., on the 28th, being 24 hours afterward, it stood 8.70 feet, thus making the quantity (delivered in 24 hours) 8,662,000 gallons.'

"'On Jan. 31, at 6 h. 15 m. P.M., the water stood 12.25 feet (above the bottom of Rush Reservoir), and on Feb. 2, at 11 h. 45 m. A.M., it stood at 15.55 feet; hence in 41 h. 30 m. the delivery was 13,999,000 gallons, which equals 8,000,000 gallons in 24 hours.'

"'On Feb. 7, at 9 h. 0 m. A.M., the water stood 16.25 feet (above the bottom of Rush Reservoir), and at 9 h. 30 m. P.M. of the same day it stood 17.35 feet; hence in 12 h. 30 m. the delivery was 4,840,000 gallons, which equals 9,292,800 gallons in 24 hours.'"

"The memoranda furthermore show that on Feb. 2, 1876, the water in Rush Reservoir stood at a depth of 15.60 feet at 2 h. 30 m. P.M., and at 15.70 feet at 3 h. 30 m. P.M., thus giving during one hour a delivery of 430,000 gallons, which is at the rate of 10,320,000 gallons in 24 hours. The duration of this observation is, however, too short to warrant much confidence in the result, since a slight error in noting the rise of

the water would make a proportionately great difference in the daily flow.

"Another gauging was made on July 21 and 22, 1876, with discharge at the same time from Rush Reservoir into Mt. Hope Reservoir."

This last gauging is then discussed, is found to have been erroneously computed, and is placed by the reporting Chief Engineer at 8,861,280 gallons in 24 hours; instead of 8,248,573 gallons, as had been reported by Mr. Nichols.

The conclusion reached is: "Taking into account the probable losses of water by undiscovered leakage from defective joints on twenty miles of newly laid conduit, also by absorption into the bed and banks of the new reservoir, etc., at the time that the gaugings were made, the conclusion now seems thoroughly justifiable that the conduit did originally have a discharging capacity of about 9,000,000 gallons per day."

Under date April 4, 1892, the same Chief Engineer reports as follows:

"Several gaugings of the discharge of the conduit into Rush Reservoir were made during the past season, and from them the delivery was found to be in the vicinity of 7,000,000 gallons per day, as was found in the previous year. Other delicate tests of the condition of the pipe were also made in the most careful manner; and from the data thus obtained, along with the records derived from the self-recording pressure-gauges at the two reservoirs, it is amply demonstrated that the flow has been practically uniform throughout the whole period, varying only in slight degree from the relative elevations of the water in the lake and the reservoir."

Under date April 3, 1893, we find this statement:

"Several gaugings of the discharge of the conduit into Rush Reservoir were made during the past season, and from them the delivery was found to range from about 6,820,000 to 6,870,000 gallons per day of 24 hours, or practically the same as was found in the previous year. From the data thus obtained, together with the records of the self-recording pressure-gauges at the two reservoirs, it is demonstrated that the flow has been practically uniform throughout the whole period, varying only in slight degree with the relative elevations of the water in the lake and the reservoir."

And under date April 1, 1896, this review of all the gaugings of the Rochester main conduit is given in Chief Engineer Kuichling's report:

"The gaugings of the discharge of the conduit into Rush Reservoir during the past season showed substantially the same delivery as during the previous year, and from the records of the self-recording pressure-gauges at the two reservoirs it is seen that the flow has been practically uniform throughout the whole period, varying only in slight degree with the elevations of the water in the lake and the reservoirs. As it may be of interest to compare the recent gaugings with those formerly made, the results of the more important observations are herewith submitted.

"It should also be noted that the heads under which the discharges took place differed somewhat, but by reducing the latter to the normal heads little difference in the results is found. Both sets of observations refer to 24-inch pipe, the length being 51,450 feet, with an average fall of 125.00 feet. This length embraces 15,419 feet of riveted wrought-iron pipe, the rest being cast iron.

STATEMENT D, SHOWING GAUGINGS OF DISCHARGE OF OLD CONDUIT BY MEASUREMENTS OF RISE AND FALL OF WATER-SURFACE IN RUSH RESERVOIR.

Date.	Section of Conduit.	Duration of Experiment, Hours.	Computed Discharge in Gallons per Day of 24 Hours.
Jan. 27–28, 1876	Hemlock Lake to Rush Reservoir	24	8.662,000
Jan. 31—Feb. 2, 1876	" " " " "	41⅙	8,000,000
Feb. 7, 1876	" " " " "	12½	9,292,800
July 21–22, 1876	" " " " "	29	8,861.280
Oct. 10, 1890	" " " " "	8	*7,185,000
Mar. 22, 1891	" " " " "	5⅙	7,142,000
Apr. 19, 1892	" " " " "	8	*6,853,500
Sept. 24, 1892	" " " " "	10⅙	*6,805,600
May 5, 1893	" " " " "	6¼	*6,900,300
June 1, 1894	" " " " "	7½	*6,807,400
Oct. 18, 1895	" " " " "	7¼	*6,660,000

NOTE.—The gaugings marked with an asterisk are gross discharges of the pipe, including evaporation from water-surface and percolation through bottom of reservoir.

"The gaugings of 1876 were made soon after the conduit was first put in operation, and while there was doubtless more or less leakage in both the pipe and the reservoir. Although not conducted with the utmost refinement of appliances and observation, they may nevertheless be regarded as fair approximations to the truth; and as they were fully discussed in the Fifteenth Annual Report of the Executive Board, made in 1891, their further consideration at the present time appears unnecessary. The gaugings made since September 1890 have been conducted with every precaution to insure accuracy, and it is confidently believed that the results are as correct as it is now possible to make such measurements. From these figures it will be noticed that a reduction in the discharging capacity of the conduit has been going on during the past twenty years, and that such reduction has not yet ceased."

This review is a little confusing. We find the statement

that "little difference in the results is found," when the discharges are reduced to the same heads acting on the pipe, during the period from Oct. 1890 to Oct. 1895. But from the tabulated figures, which are not reduced to the same heads acting on the pipe, "it will be noticed that a reduction in the discharging capacity of the conduit has been going on during the past twenty years, and that such reduction has not yet ceased."

Leaving the last five years' gaugings, as reported, out of the question, for want of sufficient data, for of course the observed discharges must be all reduced to the same head to be of any value for comparison, we may now discuss only the 1876 reported gaugings.

The first shock the discerning and fairly disposed hydraulic engineer will receive will be to observe the range of reported results, all derived from allegedly "very accurate observation of the rise of the water-surface in the Storage Reservoir"; being a range from 8 million to over 9¼ million, or about 16%. With some experience in measuring water, the author will venture to assert that three gaugings of that range of results are not worthy of the name, and should be rejected as gaugings the moment they are reported. Unfortunately, they have been with us for the past twenty years, having come in under a disguise and in a questionable manner, so that we must needs give them some further attention.

The next point that will attract notice is the fact that the heights of water are not read nearer than 0.05 ft., about ⅝ of an inch. As 0.05 ft. is equivalent anywhere from 191,214 to 217,450 gallons at the close of the several alleged gaug-

ings,* a discrepancy of 0.05 in reading the float could have made, in a 12-hour gauging, an error of nearly half a million gallons in the reported 24-hour result, and the addition of two such errors, one at the start and another at the end of the farcical performance, would have made an error of about a million gallons per 24 hours.

The next symptom that offends discerning nostrils is the circumstance that of four so-called gaugings, only the largest, based on a 12½-hour run, viz. 9,292,800 gallons, should have been reported in the 1877 Report as the "only one careful measurement" that had been made; and that all the others, including a 41½-hour run, which showed only 8 million gallons, should have been suppressed.

Let us see whether we cannot let Mr. Nichols testify. From reliable authority the author has it that in the office of Theo. Bacon, esq., of Bacon, Briggs, Beckley & Bissell, of Rochester, N. Y., could have been seen, towards the end of 1895, a stenographer's copy of certain testimony given by Mr. L. L. Nichols, the Assistant Engineer who is reported to have made the 1876 gaugings, in the case of Hiram Smith and others against the City of Rochester, in 1879, pages 375 and 376, which reads as follows:

"Question. Did you ever make any observations or tests of the discharge of water through the conduit to the city?

Answer. No, sir.

Question. Have you merely assumed certain quantities from information derived from others?

Answer. Yes, sir.

Question. You have never made any estimates yourself,

* See contents of Rush Reservoir, 1877 Rochester Report, etc.

either for the purpose of this examination or for any other purpose?

Answer. I have looked at the gauge at the reservoir, showing how much was passing.

Question. Passing into the city?

Answer. Passing into the Mount Hope Reservoir.

Question. And there is another gauge that shows how much passes into the city?

Answer. Yes, sir.

Question. And that is the means of ascertaining the amount of supply into the city?

Answer. Yes, sir.

Question. You have never computed, at any former time, the capacity for passage of the conduit?

Answer. Yes, sir, I have computed that.

Question. When did you make a computation of that?

Answer. I did it at the time the water-works were going on.

Question. What did you ascertain to be the capacity?

Answer. The conclusion I arrived at was something over 7,000,000 gallons per day.

Question. Did you not at one time reach a higher sum than that?

Answer. I did, from an experiment.

Question. When was that experiment made?

Answer. That was on the first filling of the Rush Reservoir.

Question. That was when?

Answer. In the winter of 1876.

Question. Rush Reservoir was not filled until the whole line was put in operation?

Answer. No, sir.

Question. What did you ascertain from your experiment?

Answer. The flow through the pipe, for 24 hours, was

equal to 9,000,000 gallons, or something in that neighborhood; but a trifle over 9,000,000 gallons.

Question. Is it the amount stated in Mr. Tubbs' report, as being 9,293,000 gallons ?

Answer. I think it is.

Testimony of Mr. J. Nelson Tubbs in the same suit (direct examination by Mr. Cogswell):

Question. What is the capacity of the pipes through which the water is drawn from the lake to the city?

Answer. It is stated in my report, as a matter of experiment, at a little over nine million gallons, the full capacity."

This certainly does not seem to indicate that Mr. Nichols thought any too highly of his so-called gaugings, derived from "very accurate observation of the rise of water," etc., and represented as proving to some minds, so late as 1891, that "at the time the gaugings were made the conclusion seems justifiable that the conduit did originally have a discharging capacity of about 9,000,000 gallons per day."

Does it not rather give color to the rumor that Mr. Nichols, who was in January, 1876, some 65 years old, found the work of observing a float on Rush Hill in January decidedly chilling, and illicitly delegated the disagreeable work to the gatekeeper, and that what the gatekeeper did and saw in 1876 is probably beyond the powers of anything but the most occult of sciences to determine.

If we make the liberal assumptions that the coefficient of discharge of the new 36″ wrought-iron pipe was 94, that of the new 24″ wrought-iron pipe was 100, that of the new 24″ cast-iron pipe was 122, in 1876, and that the whole available head on the conduit was 143.8 feet, a computation made on

the lines of Mr. Hering's computation in Tr. Am. Soc. C. E., 1892, I, 43, will give 8,085,424 U. S. gallons per 24 hours as the discharge of the Rochester conduit in 1876; and when vertical and horizontal curves, which were not smoothed off very well, and unavoidable hydraulic defects are taken into consideration, it is fair to assume that the conduit never carried so much as 8 million gallons per 24 hours under 143.8 feet of total head.

What more need be said about those venerable fakes called the Rochester gaugings of 1876? Only this: that it were well for hydraulic engineering if they and all trace of them could be extirpated from engineering literature. The places they have occupied should be cleansed by the use of acids. The barren spots resulting might be left as a warning to future intending evil-doers not to indulge in careless statement, or worse, in official reports and on matters of hydraulic engineering.

It is a well-known rule of law that official documents are *prima facie* evidence. But if the above exposition be considered, and it be further considered what remarkable action is so frequently taken by American municipal bodies in their conduct of public works and in their selection of public servants, it will probably be a safer rule hereafter to ignore the rule of law just quoted, and to be very shy about accepting statements of engineering data taken from American city engineering literature. There is good in it, and the indifferent; unfortunately, there is also the pestilential and the offspring of the Evil One.

CHAPTER IV.

EXPERIMENTS ON RIVETED CONDUITS, MOSTLY MADE SUBSEQUENT TO THE ROCHESTER EXPOSURE OF 1890.

> "So eine Arbeit wird eigentlich nie fertig."
> —GOETHE, 1787. *Letter.*
> (A work of this sort may be said never to be finished.)

> "The book of Nature is that which the physician (student) must read; and to do so he must walk over the leaves."—PARACELSUS, 1490–1541.

Mr. GEO. W. RAFTER, M. Am. Soc. C. E., has described the hubbub pervading the city of Rochester in the summer of 1890, when the conduit, reported as carrying 9¼ million gallons per 24 hours in 1876, failed to deliver so much as 7 million gallons per day that summer, and was gauged by him, then in charge of the Rochester Water-works, for the first time since it had been built, strictly speaking. He first showed the reason why the conduit did not—that is to say, why it could not—supply the city, and instituted measures for restricting the consumption of the city; all of which is recorded in the two papers by Mr. Rafter, Tr. Am. Soc. C. E., 1892, I. But the exposure made to the citizens of Rochester was no less an exposure made to engineers and others interested in the carrying capacity of riveted pipe, the world over, and many experiments have no doubt been made on riveted con-

duits since that time, which but for it might or would have been deemed unnecessary. These and a few of the older ones—that is to say, all attainable to the author—upon riveted conduits, from 1 foot diameter upwards, and up to 6 feet per second of velocity through them, to the number of 115, have been reduced to the same measures, and are now submitted. Among them are 84 made on the conduits of the East Jersey Water Company and now for the first time published.

REMARKS UPON THE CONDUITS REFERRED TO IN TABLE I.

The first 99 numbers have been reserved for experiments on the 48″ steel conduit No. 1 of the East Jersey Water Company. The laying of this conduit was commenced September 20, 1890; completed December 30, 1891; and the conduit put into use April 26, 1892. It is composed of alternate large and small sections or courses, the common form of construction, which for obvious reasons may be called a pipe with cylinder-joints. It is dipped in asphalt. Vertical and horizontal curves are well made, none sharper than a 10° curve, 574 feet radius, and most of them less than that. Only four kinds of curves were used: $2\frac{1}{2}°$, $5°$, $7\frac{1}{2}°$, and $10°$ curves.* From the up-stream end for 5 miles the profile is much broken, the pipe going up and down, hill after hill. It touches the hydraulic gradient seven times in this space of 5 miles, excluding the point of beginning, which last is usually under 4 or 5 feet, or more, of head. This brings the conduit to Pompton Notch. For the remaining 16 miles the profile

* Journal New England Water-works Association, Sept. 1893, and *Engineering News*, June 15, July 6 and 13, 1893. Also Foreign Abstracts, Inst. C. E., vol. 114.

Table I.

EXPERIMENTS ON CONDUITS.

1	2	3	4	5	6	7	8	9	10	11	12	13
No.	Date.	Location, Station to Station.	Length in Feet.	Thickness, Per Cent of Different Thickness of Metal. $\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	Diam. of Average Area, In Feet.	Quantity in Cu. Ft. per Sec.	Velocity in Ft. per Sec.	Loss of Head per 1000 Ft.	Comparative Weight.	Coefficient c in $v = c\sqrt{rs}$.
	48″ Conduit, No. 1.											
	CYLINDER-JOINTS.											
	1892											
1	April 10	11+50 to 257+80	24,630	100	0	0	3.96	63.2	5.13	2.07	B	
2	“ 11...	“ “ “	24,630	100	0	0	3.96	65.1	5.29	2.13	B	
3	“ 16....	“ “ “	24,630	100	0	0	3.96	66.1	5.37	2.25	B	
4	“ 18...	“ “ “	24,630	100	0	0	3.96	66.2	5.38	2.24	B	
5	“ 19 ...	“ “ “	24,630	100	0	0	3.96	66.2	5.38	2.24	B	
6	“ 20 ...	“ “ “	24,630	100	0	0	3.96	66.6	5.41	2.28	B	
	1896											
28	Jan. 5...	“ “ “	24,630	100	0	0	3.96	54.3	4.41	2.23	B	
29	“ 18....	“ “ “	24.630	100	0	0	3.96	54.9	4.46	2.24	A	
31	Mar. 26....	11+50 “ 116+57	10,507	100	0	0	3.96	57.0	4.63	2.05	A	
32	“ 26....	116+57 “ 257+80	14,123	100	0	0	3.96	57.0	4.63	2.34	A	
34	July 29 ...	11+50 “ 257+80	24,630	100	0	0	3.96	36.05	2.93	1.02	A	
35	Aug. 20....	“ “ “	24,630	100	0	0	3.96	36.65	2.98	1.03	A	
	1892											
7	April 19....	309+ 0 “ 923+55	61,455	34	19	47	3.945	66.6	5.45	2.47	A	
	1896											
20	Jan. 13....	“ “ “	61,455	34	19	47	3.945	54.7	4.47	1.91	A	
40	Sept. 23 ...	“ “ “	61,455	34	19	47	3.945	36.4	2.98	0.80	A	
41	Oct. 20 ...	“ “ “	61,455	34	19	47	3.945	53.7	4.39	1.81	A	
30	Feb. 6...	280+ 0 “1110+ 0	83,000	36	22	42	3.95	54.6	4.46	1.90	D	
33	May 31.. .	283+ 0 “ 923+55	64,055	34	19	47	3.95	70.6	5.77	3.12	A	
	1892											
8	July 16....	719+40 “1052+96	33,356	70	10	20	3.95	41.3	3.36	0.94	B	
9	“ 18....	“ “ “	33,356	70	10	20	3.95	44.5	3.62	1.00	B	
12	Sept. 5....	“ “ “	33,356	70	10	20	3.95	32.0	2.61	0.51	B	
10	July 19....	309+ 0 “1052+96	74,396	38	19	43	3.95	44.5	3.64	1.07	B	
11	Sept. 5....	309+ 0 “ 575+87	26,687	12	10	78	3.94	32.0	2.62	0.65	B	
	1893											
13	Oct. 2....	“ “ “	26,687	12	10	78	3.94	31.7	2.59	0.69	B	
14	“ 3....	“ “ “	26,687	12	10	78	3.94	34.3	2.81	0.82	B	
15	“ 12 ...	“ “ “	26,687	12	10	78	3.94	31.4	2.57	0.68	B	
	1894											
16	Mar. 22 ..	“ “ “	26,687	12	10	78	3.94	25.05	2.05	0.40	B	
17	“ 22 ..	“ “ “	26,687	12	10	78	3.94	37.15	3.05	0.94	B	
18	Nov. 17....	“ “ “	26,687	12	10	78	3.94	43.6	3.57	1.16	B	
	1896											
42	Sept. 23...	“ “ “	26.687	12	10	78	3.94	36.4	2.98	0.86	A	
19	Jan. 13....	309+ 0 “ 575+10	26.610	12	10	78	3.94	54.7	4.48	1.98	A	
43	Oct. 20....	“ “ “	26,610	12	10	78	3 94	53.7	4.40	2.03	A	
	1894											
21	Nov 17 ..	309+ 0 “1117+ 0	80,800	36	22	42	3.95	43.6	3.56	1.12	A	
	1896											
22	Jan. 13....	575+10 “ 923+55	34,845	52	25	23	3.95	54.7	4.46	1.83	A	
36	Aug. 19 ...	“ “ “	34.845	52	25	23	3.95	73.5	6.01	3.16	B	
37	“ 21 ..	“ “ “	34,845	52	25	23	3.95	74.0	6.04	3.15	A	
38	“ 25 ..	“ “ “	34.845	52	25	23	3.95	74.3	6.06	3.18	A	
39	“ 26 ...	“ “ “	34,845	52	25	23	3.95	74.1	6.04	3.16	A	
44	Sept. 23....	“ “ “	34.845	52	25	23	3.95	36.4	2.97	0.37	A	
45	Oct. 20	“ “ “	34,845	52	25	23	3.95	53.7	4.38	1.71	A	

EXPERIMENTS ON CONDUITS.

48″ Conduit, No. 1.—*Continued.*

1	2	3	4	5	6	7	8	9	10	11	12	13
No.	Date.	Location.	Length	% Thickness.			Dia.	Quan.	Vel.	Head per 1000 ft.	Wt.	*c*
				$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$						
	1893											
23	Oct. 2....	719+40 to 923+55	20,415	79	3	18	3.95	31.7	2.58	0.45	B	
24	“ 5....	“ “ “	20,415	79	3	18	3.95	31.7	2.58	0.56	B	
25	“ 11 ...	“ “ “	20,415	79	3	18	3.95	40.2	3.27	0.91	C	
	1894											
26	Mar. 26....	“ “ “	20,415	79	3	18	3.95	25.0	2.04	0.33	B	
27	Nov. 17....	719+40 “ 1117+0	39,760	62	17	21	3.95	43.6	3.55	1.08	A	

36″ Conduit.

CYLINDER-JOINTS.

	1892											
101	April 21....	Gate-house to gate-house	25,000	100	0	0	3.00	40.3	5.70	2.86	C	
102	“ 21....	do.	25,000	100	0	0	3.00	33.6	4.75	2.35	C	
103	“ 21....	do.	25,000	100	0	0	3.00	26.6	3.76	1.59	C	
104	“ 21 ..	do.	25,000	100	0	0	3.00	19.7	2.79	0.97	C	
105	“ 21....	do.	25,000	100	0	0	3.00	13.2	1.87	0.55	C	
106	“ 21....	do.	25,000	100	0	0	3.00	7.9	1.12	0.20	C	
107	“ 21....	do.	25,000	100	0	0	3.00	4.0	0.56	0.04	C	
	1896											
108	Feb. 6....	1110+30 to 1357+50	24,720	100	0	0	3.00	34.8	4.93	2.87	A	

42″ Kearney Extension.

TAPER-JOINTS.

	1896											
150	Jan. 21....	4+11 to 59+85	5,574	23	55	22	3.50	17.4	1.81	0.33	B	
151	“ 25...	“ “ “	5,574	23	55	22	3.50	17.3	1.80	0.40	B	
152	“ 25....	“ “ “	5,574	23	55	22	3.50	19.55	2.04	0.32	B	
153	“ 27....	“ “ “	5,574	23	55	22	3.50	34.7	3.61	1.15	B	
154	“ 27....	“ “ “	5,574	23	55	22	3.50	31.1	3.23	1.05	B	
155	“ 29...	“ “ “	5,574	23	55	22	3.50	29.7	3.09	0.80	B	
156	“ 29 ...	“ “ “	5,574	23	55	22	3.50	35.2	3.66	1.12	B	
157	“ 30. .	“ “ “	5,574	23	55	22	3.50	17.5	1.82	0.53	B	
158	“ 30....	“ “ “	5,574	23	55	22	3.50	19.8	2.06	0.60	B	
159	Nov. 18....	“ “ “	5,574	23	55	22	3.50	41.0	4.26	1.80	A	

48″ Conduit, No. 2.

TAPER-JOINTS.

	1896											
200	June 19....	12+50 to 258+98	24,648	99	0	1	3.96	57.7	4.69	1.96	B	
201	July 29....	“ “ “	24,648	99	0	1	3.96	36.8	2.99	0.89	A	
202	Aug. 13...	“ “ “	24,648	99	0	1	3.96	37.1	3.01	0.90	A	
203	“ 20....	“ “ “	24,648	99	0	1	3.96	37.25	3.03	0.89	A	
204	Oct. 22....	“ “ “	24,648	99	0	1	3.96	48.0	3.90	1.40	A	
205	“ 23....	“ “ “	24,648	99	0	1	3.96	56.7	4.61	1.99	A	
206	Sept. 24 ...	“ “ “	24,648	99	0	1	3.96	57.95	4.71	2.04	B	

EXPERIMENTS ON CONDUITS.

42″ CONDUIT, NO. 2.

TAPER-JOINTS.

1	2	3	4	5	6	7	8	9	10	11	12	13
No.	Date.	Location.	Length	% Thickness.			Dia.	Quan	Vel.	Head per 1000 ft.	Wt.	*c*
				1/4″	5/16″	3/8″						
	1896											
257	Sept. 9....	611+01 to 1109+34	49,833	71	38	1	3.50	16.8	1.75	0.32	B	
258	" 10 ...	469+07 " "	64,027	67	32	1	3.50	13.45	1.36	0.19	B	
259	" 11....	297+95 " "	81,139	54	45	1	3.50	21.3	2.21	0.52	B	
260	" 18 ...	" " "	81,139	54	45	1	3.50	29.0	3.02	0.93	B	
261	" 19....	" " "	81,139	54	45	1	3.50	37.5	3.90	1.45	B	
262	" 21....	" " "	81,139	54	45	1	3.50	45.1	4.69	2.14	C	
263	" 23....	" " "	81,139	54	45	1	3.50	44.15	4.59	2.04	B	
264	Oct. 15....	" " "	81,139	54	45	1	3.50	45.25	4.70	2.18	A	
265	" 16....	" " "	81,139	54	45	1	3.50	41.3	4.29	1.80	A	
266	" 17....	" " "	81,139	54	45	1	3.50	34.95	3.63	1.31	A	
267	" 19...	" " "	81,139	54	45	1	3.50	28.0	2.91	0.85	A	
268	" 20....	" " "	81,139	54	45	1	3.50	20.25	2.10	0.47	A	
270	" 22....	" " "	81,139	54	45	1	3.50	48.0	4.99	2.40	A	
269	" 20 ..	611+01 " "	49,833	71	38	1	3.50	9.25	0.96	0.907	A	

See "Hydraulics," by HAMILTON SMITH, Jr., 1886; also Tr. Am. Soc. C.E., 1883 and 1884.

	1873–1879...	California	12,798 to 684.8	0.165 to 0.065			2.40 to 0.91	50. to 3.07	20.14 to 4.38	66.72 to 6.68	A to B	

TAPER-JOINTS.

344	1876 October	North Bloomfield, Cal.	731	0.065 to 0.083			0.91	3.07	4.71	8.50	B	107.1
343	"	do.	721	"	"	"	0.91	3.97	6.09	13.34	B	110.6
348	"	do.	718	"	"	"	1.06	4.02	4.59	6.68	B	109.4
347	"	do.	709	"	"	"	1.06	6.10	6.96	14.28	B	113.4
354	"	do.	720	"	"	"	1.23	5.20	4.38	5.02	B	111.6
353	"	do.	712	"	"	"	1.23	8.13	6.84	10.97	B	117.8

16″ CONDUIT AT ASTORIA CITY. (See Tr. Am. Soc. C. E., April 1896.)

CYLINDER-JOINTS.

				No. 10	No. 12							
401	1895 Dec.	....	16416.38	50	50	..	1.33	6.37	4.58	5.0023	B	110

108″ CONDUIT AT HOLYOKE. (See Tr. Am. Soc. C. E., Nov. 1887.)

CYLINDER-JOINTS. 3 PLATES PER CIRCLE.

					1/2″							
501	1887 October.	....	152.88	...	100	...	8.615	......	0.5	0 0078	B	126.5
502	"	....	152.88	....	100	..	8.615	.....	1.0	0.0320	B	116.6
503	"	....	152.88	...	100	....	8.615	......	1.5	0.0822	B	112.7
504	"	....	152.88	....	100	....	8.615	......	2.0	0.1532	B	110.3
505	"	....	152.88	....	100	...	8.615	......	2.5	0.2421	B	108.8
506	"	....	152.88	....	100	....	8.615	......	3.0	0.3520	B	107.7
507	"	....	152.88	...	100	...	8.615	.....	3.5	0.4902	B	106.9
508	"	....	152.88	....	100	..	8.615	.....	4.0	0.6520	B	106.2
509	"	....	152.88		100		8.615	.....	4.5	0.8350	B	105.6

EXPERIMENTS ON CONDUITS.

DARCY. "Conduite No. 10," Mouvement de l'Eau dans les Tuyaux, 1857. (See also HAMILTON SMITH'S "Hydraulics," p. 226.)

SCREW-JOINTS.

1	2	3	4	5	6	7	8	9	10	11	12	13
No.	Date.	Location.	Length	% Thickness.			Dia.	Quan	Vel.	Head per 1000 ft.	Wt.	*c*
601	1850	Paris	365.5	....	(?)	....	0.935	......	1.30	0.7	B	101.3
602	....	....	365.5	....	....	....	0.935	......	2.78	2.5	B	114.0
603	....	....	365.5	....	....	....	0.935	......	3.87	4.3	B	121.6
604	....	....	365.5	....	....	....	0.935	......	4.90	6.8	B	122.5
605	....	....	365.5	....	....	....	0.935	......	6.67	11.9	B	126.5

GEO. W. RAFTER, July and August, 1890, and EMIL KUICHLING, 1891, and subsequently.

ROCHESTER, N. Y., CONDUITS.

CYLINDER-JOINTS.

701	1890 July & Aug.	Conduit used since 1876	50,819	3/16"			3.00	10.43	1.47	0.45	C	80.4
702	" " "	do.	1,901	3/16" and 1/4" % each (?)			2.00	10.43	3.32	3.83	C	76.0
703	" " "	do.	10,541	do.			2.00	10.43	3.32	3.58	C	78.5
704	1891 Oct. 14, " 15, " 16	do.	3,327	do.			2.00	10.52	3.35	3.46	B	80.5
705	do.	do.	50,820	3/16"			3.00	10.52	1.49	0.43	B	83.0
706	1895 Oct. 4....	Conduit completed Aug. 24, 1894	91,641	71	24	5	3.17	25.78	3.27	0.99	A	116.6
707	Dec. 23....	do.	91,641	71	24	5	3.17	25.45	3.23	1.01	A	114.0
708	Oct. 17 ...	do.	45,400	29	28	43	3.17	30.53	3.88	1.59	A	109.3
709	" 26...	do.	45,400	29	28	43	3.17	30.78	3.91	1.61	A	109.3
710	Nov. 7 ...	do.	45,400	29	28	43	3.17	30.74	3.90	1.62	A	109.1

In the above table,

A denotes experiments in which all the conditions were favorable, and all the observations were complete, and in which no disturbing causes were known or suspected.

B denotes good experiments; they may be just as good as those marked A, but the observations were not so complete, or were fewer in number.

C denotes experiments in which disturbing causes were known to exist, which may have vitiated the results.

D denotes experiments of little value, depending on a few observations, or otherwise defective.

is much less broken, and the conduit does not again touch the hydraulic gradient. On this length of 16 miles it is in effect one long "inverted siphon," although it crosses two marked high hills.

As the hydraulic gradient commences at the level of the top of the pipe at the intake, the pipe was run with a head on all the points where it touches the theoretical hydraulic gradient, between the intake and Pompton Notch, except on the last stretch of hydraulic gradient, in the Notch itself. Owing, no doubt, to the well-known fact that a pipe will discharge more when filled up to about 0.95 of its diameter than when full, other things being equal—that is to say, will discharge a given quantity of water easier, or, in other words, with less work, when 0.95 full than when full—this length in Pompton Notch was never quite full until after May 30, 1896. On that date, 48″ conduit No. 2, running parallel with and alongside of conduit No. 1, from the intake to Pompton Notch, was completed, and was immediately turned into No. 1 at Pompton Notch. This put a head on No. 1 at the Notch, and naturally filled it, up-stream from the Notch. It also increased the discharge of No. 1 down-stream from the Notch, to delivery at Belleville; the object of the manœuvre described.

The rivet-heads, whether exterior or interior, were all well-formed. Shop-rivets had been driven with a hydraulic riveter; field-rivets with a cup, or set. All plate-edges had been bevel-planed. The author knows no reason why this conduit should not even now be held to conform to the Hamilton Smith specifications for pipe to which was said to be applicable the table on p. 271 of "Hydraulics."

"The given values of c can, in our judgment, be used with entire safety for computing the flow of reasonably clean water, either through well-made cast-iron pipes, or through riveted sheet-iron or steel pipes, where the rivet-heads do not form quite a notable portion of the area. The pipes must be properly coated with a varnish of asphaltum and coal-tar, or some other preparation equally good; the joints must be smoothly united, and any curves must be well rounded. These remarks apply to diameters from 1 to 8."

Nos. 100 to 149 refer to the 36″ conduit of the East Jersey Water Company running from Belleville to South Orange Avenue. The remarks above made respecting construction of the 48″ conduit No. 1 apply to this 36″ conduit also. It was first filled with water February 15, 1892. In profile it is a long inverted siphon, about 5 miles long, with only one sharp valley to cross. Most of it being laid in city streets, the horizontal curves have a smaller radius than has been hitherto spoken of. There are two curves of 83 feet radius, one of 75 feet, two of 65 feet, and one of 41 feet radius, but they are all well rounded and smoothly finished.

Nos. 150 to 199 refer to what is called the "Kearney Extension" of the East Jersey Water Company, a 42″ riveted steel conduit which runs from Belleville across the Passaic River to Kearney. In profile it is a single inverted siphon, with a few horizontal curves. It is about 9000 feet long, of which 6000 feet are on the Belleville side of the river. The river is crossed by seven parallel lines of 16″ lap-welded, screw-jointed, steel pipes, hauled across on the bottom of the river, in a trench dredged for the purpose. The experiments

PLATE I.

INTERIOR VIEW OF 42″ CONDUIT NO. 2 OF THE EAST JERSEY WATER CO., 1896. (Looking up-stream.)

[*Facing page* 33.]

reported were all made on the Belleville side of the river, and up-stream from the intake of the seven 16″ pipes.

This 42″ conduit is not built with cylinder-joints. Instead was used the form of joint sometimes called a "stove-pipe" joint, in which the down-stream small end of each section, or course, is fitted into the up-stream large end of the succeeding section. This form will here be called a "taper-joint," which is the shop-name for such work. In other respects, the remarks already made concerning methods of construction of riveted conduits will apply to the 42″ Kearney Extension conduit as well. The coating of this conduit, which was laid in the late fall and winter, was unusually smooth. It was put into use January 10, 1896.

Nos. 200 to 299 refer to conduit No. 2 of the East Jersey Water Company, running parallel with and alongside of conduit No. 1. 28,200 feet are 48″ conduit, from the intake to Pompton Notch, being Nos. 200 to 249; and the remainder, 82,800 feet, is a 42″ conduit, being Nos. 250 to 299. Both the 48″ and the 42″ parts of conduit No. 2 are built with taper-joints. Pipe-laying commenced in March 1896, three canal crossings being laid that month; it was completed, and the conduit put into use to Pompton Notch, on May 30, 1896; and completed to Belleville, and put into use for its entire length, on September 30, 1896.

Nos. 300 to 399 refer to conduit experiments described in Hamilton Smith's "Hydraulics." They bear the same numbers here that they do in that treatise. These are taper-joint riveted pipe, dipped in asphalt, and as good as new.

Nos. 400 to 499 have been reserved for recent experiments. Only one has been found in engineering literature

devoid of stated defects: on the pipe at Astoria, Oregon, see Tr. Am. Soc. C. E., 1896, 1, 226. This is a new 16″ pipe, with cylinder-joints, dipped in asphalt.

Nos. 500 to 599 refer to the author's test of a 108-inch trunk in Holyoke, Mass. See Tr. Am. Soc. C. E., November 1887. This wrought-iron pipe has cylinder-joints, and each course is composed of three plates. It had little, if any, of the original paint-coating left when tested. At date of testing it had been in use some five years, and was rather rusty inside, although not affected with the tubercular disease which is the bane of cast-iron pipes.

Nos. 600 to 699 refer to experiments on a 11¼-inch riveted pipe detailed in Darcy, "Mouvement de l'eau dans les tuyaux" (Paris, 1857). It is not recorded whether this pipe was corroded, or how much, or what the form of the joints was, except that they were screw-joints. Presumably the pipe was in good condition, and smooth at the joints. *

Nos. 700 to 799 refer to experiments made on Rochester conduits Nos. 1 and 2.

No. 1 Rochester Conduit, completed in January 1876, is a cylinder-jointed wrought-iron pipe. When laid it was dipped in asphalt, and in 1891 and 1892 was in excellent condition on the exterior. Two 20″ disks cut out of the pipe at that time showed the interior also to be in excellent condition. Judging by the appearance of these two sections, the asphalt coating has a great many wrinkles in it.

Rochester Conduit No. 2 is a cylinder-jointed, riveted

* Pipes and joints of this sort are described by Darcy in his treatise on "Les Fontaines publiques de la ville de Dijon" (1856), p. 632, which were presumably the same.

steel pipe, and was completed August 24, 1894. The January 1896 report of the Chief Engineer of Water-works, Rochester, N. Y., Mr. Emil Kuichling, contains a full description of it.

CHAPTER V.

Q AND h.

" quid nobis certius ipsis
Sensibus esse potest, quo vera ac falsa notemus ?"
—LUCRETIUS, 99–55 B.C. *De Natura rerum*, Lib. I. 703.

(What better than the senses can enable us to
istinguish the false from the true ?)

" Truth is truth,
To the end of reckoning."
—*Measure for Measure*, Act V., Sc. 1.

THE determination of the quantity flowing through a pipe has ordinarily been effected in many ways, and it will be proper to review the 115 experiments above given, with respect to the method used in each of them to measure the quantity of water flowing through the pipe. A similar review must also be given of the measurements of h, or of the total head consumed on the length of pipe under experiment to overcome resistances to flow, commonly, though incorrectly, called friction.

Nos. 1–99 and 150–299 had Q measured with a Venturi meter; Nos. 100–149, over an imperfect weir; Nos. 300–399, over weirs described in Hamilton Smith's " Hydraulics," Chap. X; Nos. 500–599, over an accurate weir in the Holyoke Testing-flume; see Tr. Am. Soc. C. E., Nov. 1887; and

Nos. 401, 600–699, and 700–799 had Q measured in tanks or reservoirs.

This art of measuring water is one that is thoroughly understood by comparatively few, even among engineers, although the present age is making rapid advances in this line as in others, more engineers are practising it, and much more attention is now bestowed upon the subject in schools than formerly, thanks to engineering and hydraulic laboratories or observatories. The author will refer in this connection to his lecture on "Measuring Water" delivered before the students of the Rensselaer Polytechnic Institute of Troy, N. Y., January 25, 1895, and printed in *The Polytechnic* of that school, March 23, 1895. Also reprinted by the Builders' Iron Foundry of Providence, R. I. It is again reprinted in the Appendix, Note C.

As the oldest and simplest method, and the one lying at the foundation of all the others, we may first examine the measurements made in tanks or reservoirs. At first thought it might seem that such a measurement must of necessity be absolutely correct, but reflection will at once show that no measurements whatever are absolutely correct, least of all those in which are involved the three dimensions of length, breadth, and thickness, together with a fourth dimension, that of time. The accuracy of any simple measurement will always depend on the accuracy of the scale, or instrument, with which the measurement is made, and also on the skill of the operator. In this way a reservoir measurement, as we have seen, when conducted by a careless engineer, or by an incompetent gatekeeper, may be little better than a guess, while the complex operation of conducting a weir-gauging can, by perfec-

tion of apparatus and skill of the operator, be made to result in a measurement that will be true within ± 1 or 2 per cent.

No precise details are given, in the source quoted, of the Astoria gaugings for No. 401, but there is no reason apparent for questioning them. Engineers have not yet got into the habit, like astronomers, of attaching a ± sign to important data, with a numeral indicating the limits within which the measurement is probably correct. In default of such an estimate of the accuracy of the present gauging by the engineer who conducted it, it has been marked B.

Q of Nos. 600–699 may be considered as having been accurately measured in tanks of moderate dimensions.

Nos. 700–799 were measured in a reservoir in which 0.1 ft. was equivalent to some 400,000 gallons. Nos. 701–703 are based on an average of four gaugings, three of which were of 12 hours' and one of 24 hours' duration. Mr. Rafter claims them to be correct within 2 or 3 per cent, which may readily be allowed. Nos. 704–710 are based on gaugings of from 5 to 8 hours' duration. Heights of reservoir-surface were measured with a hook-gauge. That the results are stated in foot measure to five places of decimals should delude nobody. A hook-gauge will not measure water-heights so that the fourth place of decimals of foot-measure can be read with certainty, and the fifth place is beyond its ken. Usually the fourth place is set down as either 5 or nothing. 5 in the fourth place is, however, 100 times more accurate than 5 in the second place, which enables a comparison to be made between the accuracy of the gaugings of 1891 and that of the so-called gaugings of 1876: about 266 cubic feet for a 0.0005 ft., as compared

with 26,666 cubic feet for a 0.05 ft. rise or fall in the reservoir. This illustrates, also, the care that must be taken in measuring water-heights when one undertakes to meter the flow of a 36″ or 38″ pipe by means of the rise of water in a 13-acre reservoir. Q in Nos. 704–710 is probably correct within 1 or 2 per cent.

The weir used for expeiiments Nos. 500–599 gave results probably correct within 1 or 2 per cent. Those used for experiments Nos. 300–399 gave results probably correct within 3 or 4 per cent. But it is impossible to say what accuracy was attained by the weir measurements of experiments Nos. 100–149, except from the measure of their agreement with No. 108, which was made in 1896, and the Q of which was measured with a Venturi meter. Few engineers, even hydraulic or water-works engineers, realize to what extent a weir measurement, to make the result accurate, must be an exact repetition or close imitation of some other weir measurement, made perhaps fifty years before, but used as the basis on which was founded the weir formula proposed to be used. Without such close imitation the proposed formula does not apply, and modern experiment has abundantly shown that a very little variation in weir construction, or proportional measurements of the weir, and of the water passing over, will make a serious difference in the results.* The fact is that the flow of water over a weir is one of the most capricious, complex, changeable forms of the flow of water which we have, and one that cannot be relied upon to give true results except when handled by experts. As well were it to assume that because a violin

* See Bazin, in Annales des Ponts et Chaussées, 1894.

is a choice musical instrument, all notes produced upon it are true in sound and volume. On the other hand, as will be shown presently, given a Venturi meter once set in line of a pipe, and a true gauging is as easily made as striking a correct chord or note on a piano.

The weirs used in experiments Nos. 100–149 are some of the permanent iron weirs set in the terminal gate-house at South Orange Avenue.* Their use is to keep a rough check on quantities delivered or wasted, so as to enable the gate-keeper, from the gate-house, to control the flow of water; or to indicate changes in quantity at the gate-house; accurate measurements being made by Venturi meters set in the pipe-line. It would have been impracticable, both on account of expense and because the gate-house could not be put out of service, to make the changes needed to convert these weirs into weirs built in conformity to the requirements of the Francis or any other weir formula; and at the time, the present form of Venturi meter register had not yet been invented. The 36″ conduit being under some 150 ft. head at the point where its Venturi meter is set, open glass tubes to measure head could not be used, and there was no time to construct a pressure-difference gauge that was thought of, to be formed by joining the upper ends of two such tubes, and forcing air into the junction-member.†

Thus it has come about that only an incomplete set of gaugings represent experiments on the 36″ conduit when it

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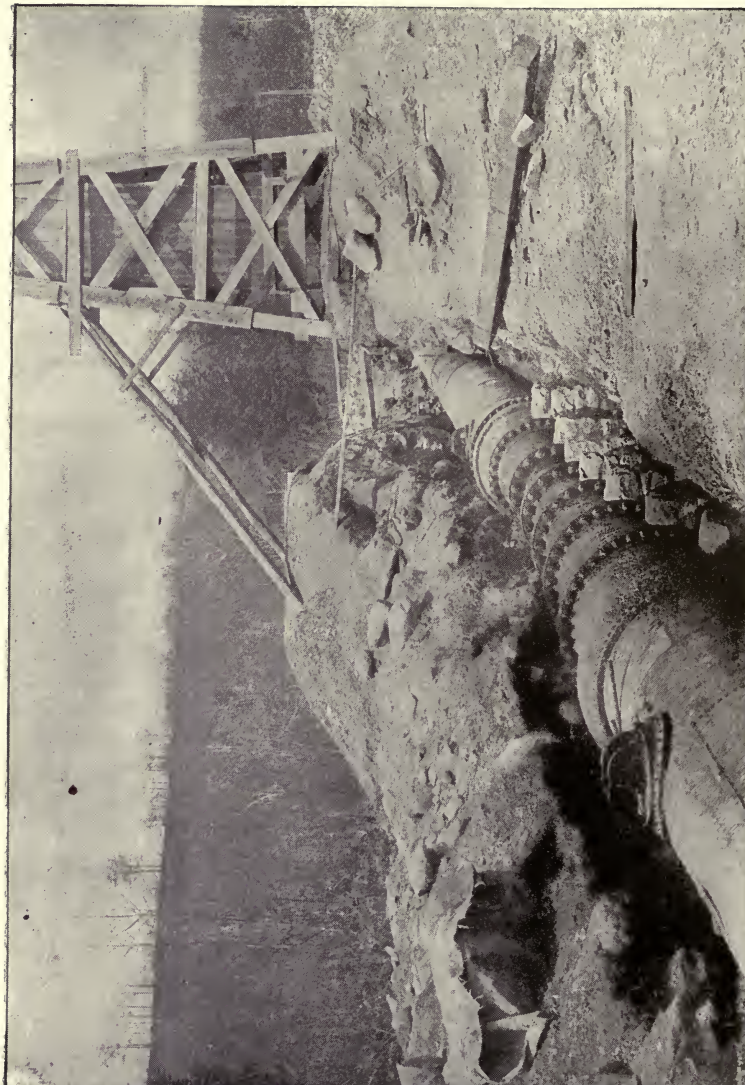
* Journal N. E. Water-works Association, Sept. 1893, Plate 36. See also *Engineering News*, June 15, July 6 and 13, 1893.

† A form of pressure-difference gauge, designed by Emil Kuichling, M. Am. Soc. C. E., which uses two connecting tubes of mercury, is described by him in Tr. Am. Soc. C. E., May 1892.

PLATE II.



48″ VENTURI METER SET IN LINE OF 48″ CONDUIT NO. 2.
The tower is used to take glass-tube piezometer readings on both 48″ meters set near it.)

[*Facing page* 41.]

was new. And although the depths upon the weir were measured with a hook-gauge, the construction of the weir was far enough from the form prescribed by the experiments on which was founded the Francis formula to make our only basis for judging the degree of approximation to the truth attained by the results, the measure of agreement of one such result with another found by means of the Venturi meter, some five years later. Nos. 100–149 have accordingly been marked C, with the exception of 108, which is entitled to be marked A.

There remain Nos. 1–99, 150–199, and 200–299, in which Q was measured with a Venturi water-meter. The Sept. number, 1893, Journal N. E. Water-works Association, shows the 48″ Venturi meter of conduit No. 1, built up of wood, with a cast-iron, brass-lined throat-piece, inside of the 48″ steel pipe; together with a discussion of this form of meter.* This paper shows also the 36″ meter used in experiment No. 108; and the meters used in experiments Nos. 150–299 were precisely similar to that used in No. 108.

The author has made three accurate sets of experiments upon the discharge of a 12″, a 48″, and a 108″ Venturi meter respectively, and upon the head acting on the throat, as well as that lost in passing the meter. These are recorded in the publications that have been cited. Besides these experiments, many of the parties who have set these meters and are using them in their daily practice have themselves tested them, both as to accuracy of gauging and as to

* See also Tr. Am. Soc. C. E., Nov. 1887; Merriman's "A Treatise on Hydraulics" (John Wiley & Sons, N. Y., 1895); publications by the Builders' Iron Foundry of Providence, R. I., U. S. A.; *Engineering* (London,) Aug. 14, 1896; *Engineering News* (New York), June 15, July 13, 1893.

insignificance of head lost in passing the meter.* The time has gone by when there is any room for questioning the accuracy of this simple instrument when used to measure either water or air—though not a pump-mixture of the two, as has at times been expected of it. Nor is there room for being carried away by first impressions as to the head lost in passing the meter. There are plenty of careful experiments extant upon both these classes of measurements, which surely might be allowed to control the first computations or crude ideas of those who have not yet become acquainted with the subject-matter.

But inasmuch as such false theorizing and such distorted views are yet occasionally met with even in print, the "old, old story" will have to be told again, in this essay, for the sake of completeness.

Plate I shows the results of the three tests of Venturi meters above referred to. The quantities passing the 12″ meter were accurately measured in a masonry tank lined with a smooth cement coating; those passing the 108″ meter, over a carefully constructed and operated weir; those passing the 48″ meter, also over a carefully constructed and operated weir. The 48″ meter was set, when tested, in the position it still occupies, in line of conduit No. 1 of the East Jersey Water Company, 1100 ft. downstream from the Intake Gate-house. The weir was set up in a temporary open flume immediately adjoining the gatehouse. The same water first passed the weir, then entered

* Prof. W. C. Unwin testifies to this last, as an eye-witness, in Min. Proc. Inst. C. E. 1895–1896, Part IV. p. 90. His remarks refer to the 48″ meter on conduit No. 1.

PLATE III.

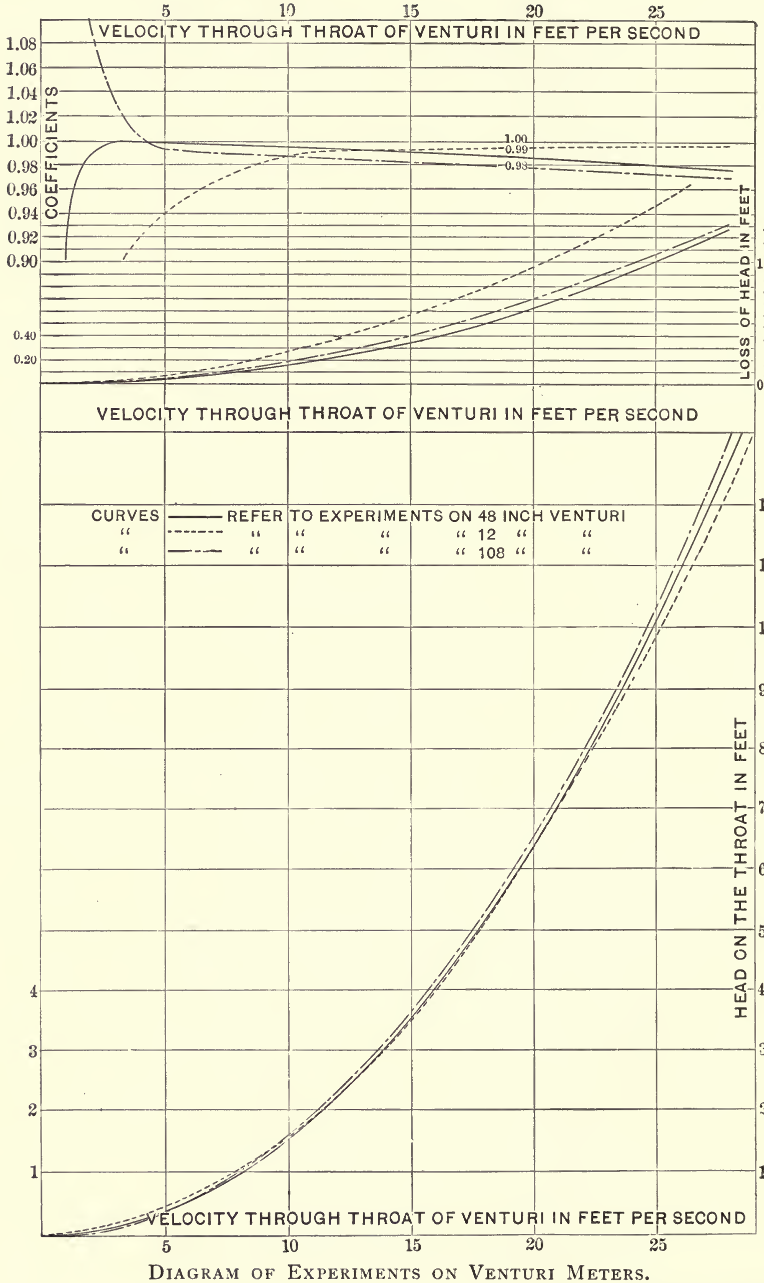


DIAGRAM OF EXPERIMENTS ON VENTURI METERS.

[*Facing page* 43.]

conduit No. 1, and 1100 ft. farther down-stream passed through the 48″ meter. Incidentally it may be mentioned that 21 miles farther down-stream the same water now passes, in the operation of the works, another 48″ meter set in line of conduit No. 1; a 16″ and a 12″ branch between the two 48″ meters are likewise metered, and all these meters check up; or failing to check, indicate what, if any, leakage exists out of the 21 miles of conduit No. 1. No. 2 conduit is similarly fitted with a meter at each end, Kearney Extension has two such meters on it, the 36″ conduit has one; and generally, the East Jersey Water Company keeps an account and a record of the details of the disposal of its total output of water. It is enabled to do so wholly by means of its ten Venturi meters; and the agreement of these meters among themselves is a constant proof of their accuracy.

The three meters tested were widely different in interior finish. The 12″ was made of wood, water-logged before it was cut to shape, carefully planed, and otherwise smoothed up inside, with a brass-lined throat-piece. The 108″ meter had a brass-lined throat-piece, but the two cones were made of board slats set around the circumference of the cone, and fastened to circular rings, or ribs, with 1/4″ spacing, so as to let the water or air pass freely behind the cones when the meter was first filled or emptied. The 48″ meter resembled the 12″ meter in interior finish. It will be noted that, notwithstanding these differences of construction, and notwithstanding the different methods used to determine the quantity passing the weir, the results are closely identical. If h represents the difference of pressure at the inlet and at the

throat, irrespective of the fact whether one or both of these pressures themselves be positive or negative, the discharge of the meter is, theoretically, $Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$, in which a_1 is the area at the inlet, and a_2 the area of the throat. Practically, we must use a coefficient of reduction, whose range is, however, surprisingly small.

As will be seen from the diagram, this coefficient between the limits of 8 ft. velocity through the throat (0.9 ft. velocity in the pipe) and 28 ft. velocity through the throat (3.1 ft. velocity in the pipe) ranges only between 0.97 and 1.00 *for all three meters.* In practical use, the variation of the coefficient with the different rates of flow is allowed for, both when computing the discharge or in the construction of the register to be used with the meter. These meters, to read right, after they are once properly set, need only be kept free of entrained air, which is done by occasionally letting water run through the pipes connecting the meter to the register. They are correct in practice easily within 1 per cent.

The loss of head in passing the meter is insignificant. In practice it need never exceed one foot, or about half a pound, and is generally only a few inches of water-pressure. Plate I shows this loss of head as measured during the experiments on the 12″, 48″, and 108″ meters.

We pass now to a consideration of the measurement of h during the 115 experiments.

Nos. 300–399 give h as computed from the total head between the water-surface at the intake to water-surface at the outlet, or to the centre of outlet.

No. 401 gives h as levelled between the water-surface in

open "stand-pipes" of 4″ or more diameter. One would think that such stand-pipes would labor under the disadvantage of being afflicted with considerable fluctuations of level, which may have been checked, however; or removed by arithmetical averaging.

Nos. 500–599 give h as measured with hook-gauges, using still-boxes of some two square feet area of water-surface. The connections between the interior of the conduit and the still-boxes were carefully made at selected points, and smoothed off on the inside of the conduit, all as described in Tr. Am. Soc. C. E., Nov. 1887.

Nos. 600–699 give h as measured by mercury columns or water-piezometers. Respecting the connection between the pipes and the piezometer-tubes, it is stated, p. 33, "Mouvement de l'eau dans les tuyaux," as follows: "On cast-iron pipes 3/8″ thick or over, the taps screwed in for purposes of attaching piezometers were filed out rounding across their inner end, following the curvature of the interior surface of the pipe, and the length of thread of the screw was exactly calculated to cause this end to come flush with this interior surface. On pipes of less than 3/8″ thickness, and on the asphalted sheet-iron pipes, the ferules were soldered on to connect with a hole about 1/8″ in diameter." To accept these data we shall have to suppose that inspection of the interior surface, after screwing in the tap or soldering on the ferule, showed that the intent of a smooth interior surface had been accomplished, because without such inspection it would be very difficult to give the exactly proper number of turns to such a tap to cause its hollowed-out end to exactly coincide with the interior surface of the pipe, or to

be sure of no trouble from solder or inside burr. Some of Darcy's piezometric results are quite discordant, as shown in Hamilton Smith's "Hydraulics" and by Hagen, and lack of good piezometer attachment attained, in spite of stated knowledge of its importance, may have been the cause of this. It should be noted, in this connection, that Darcy rejected two series of experiments on sheet-iron asphalted pipe on account of the discovery by him of the lack of such good piezometer attachments at the close of the experiments. The series here used has been marked B. The matter of a proper or the best form of piezometer attachments will be referred to later on.

Nos. 701–703 give h as measured by pressure-gauges. These measurements have been severely and, in the author's opinion, unfairly criticised in the heat of the discussion which is recorded in Tr. Am. Soc. C. E., 1892, **1**, containing also Mr. Rafter's rejoinder. The author thinks that, as regards values of h, he has perhaps unduly criticised them by marking them C, especially Nos. 701 and 703, which covered lengths of conduit 10 miles and 2 miles long, respectively. The results of these experiments, as will be noted, are in fair conformity with those found by later experiments, conducted more deliberately and with better apparatus.

No. 704 gives h as measured with the difference pressure-gauge of Mr. Kuichling already above referred to and described in Tr. Am. Soc. C. E., May 1892. With the piezometer attachments properly and carefully made, as was probably done, this must result in an accurate determination of h.

No. 705 gives h as determined between two water-surfaces by spirit-level.

Nos. 706–710 give *h* as reported in the January 1896 Report of the Chief Engineer of Water-works of Rochester, N. Y. It is the difference in elevation of two water-surfaces from 9 to 18 miles apart. The author has marked these experiments A.

Nos. 1–299 give *h* as measured by a good make of Bourdon gauges, which were tested at about the pressure at which they were to be used, before and after experimenting, by means of a Crosby gauge-tester. No single reading is probably in error over 1/2 lb., or about 1 ft.; and when it is considered that the lengths were never less than a mile, and ranged up to 16 miles, no fault can be found with this uncertainty in a single observation of one foot in height. For it must be noted that each experiment includes many readings at each station and the reading of pressures at some eight or nine intermediate points, and that careful plots were made of each which showed no marked errors in profile alignment.

These measurements were all taken in the field by Mr. J. Waldo Smith, M. Am. Soc. C. E., the earlier ones at his own instance, the later ones in pursuance of a settled determination on the part of the East Jersey Water Co. to get at all the main facts bearing on the discharge of riveted conduits. Mr. Smith has been an assistant of the author for the past twelve years, in Holyoke, Mass., and on the work in New Jersey, and is an accomplished student and observer of hydraulic phenomena. In some of the later experiments a part of the observations were taken by Mr. Winslow H. Herschel (Harvard, 1896), well fitted by previous experience for that work.

It should also be noted that extra pains were taken to

keep the pressure at the down-stream end of the conduit constant during experiments. This was done by stationing a gatekeeper to watch the gauge and keep it steady by opening or throttling the discharge, the major part of which is ordinarily controlled by pressure-regulators. This insures a constant discharge of the conduit no less than, and because of, a constant hydraulic gradient.

The marked weights to be given the several experiments sufficiently indicate the author's estimate of their accuracy and value.

This may be a proper place to discuss forms of piezometer and methods of piezometer attachment.

In the first place, at what point in the circumference of a pipe should it be tapped? The author has shown in his original paper on the Venturi Meter, Tr. Am. Soc. C. E., Nov. 1887, that piezometers tapped into a pipe at different points in the circumference do not read alike. This statement must not be confounded with the case wholly foreign to the construction of true piezometers, which considers the effect of tapping a small tube or branch into a pipe at an angle with the axis of the pipe; a misconception of terms unhappily injected into such a discussion on p. 303, Tr. Am. Soc. C. E., July 1896. The piezometers now spoken of are all at exact right angles to the "flow of the stream"; they are all smoothed off inside the pipe, and made flush with the smooth interior surface of the pipe, and yet they do not read alike.

Insertion at the zenith should be excluded, because then they are sure to give trouble from air-bubbles rising in them. As to choice of position elsewhere around the circumference, the author knows of no conclusive experiments. Such are,

however, much needed, and will be furnished from some of our hydraulic laboratories before long, it is to be hoped.

The next question that confronts one is as to the proper diameter of the tap. For some reason old experimenters have had the feeling or notion that this tap must be very minute, 1/8″ in the Darcy experiments above referred to. On the other hand, one-inch taps have given accordant results, no less than 4″ and larger stand-pipes. So far as the author knows, the only objection to large taps or stand-pipes would be the unavoidable oscillation of the water-surface in them, inherent to and an accompaniment of all flowing water, which it would then be necessary to observe and average arithmetically, or else average mechanically.

This last is ordinarily done by placing a stopcock somewhere in line of the piezometer connection, and throttling it, until the area of the inlet has so small a ratio to the cross-section of the water-column to be observed, that these oscillations practically disappear. Or, as was done in experiments Nos. 500–599, the cross-section of the water-column is, to begin with, made large enough to allow of only minute oscillations in height during the experiment.

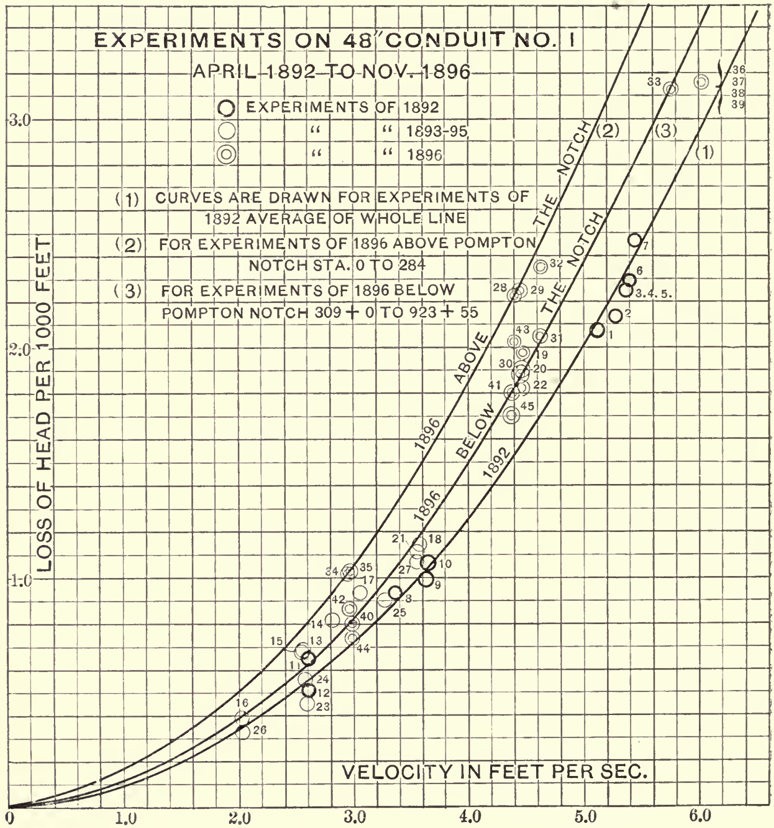
In the original paper on the Venturi Water-meter, already referred to, is described the method therein adopted for equalizing unknown disturbing causes that might affect the indications of a single piezometer attachment, by making several, 4, 5, 6, 7, or 8 such at any cross-section, leading them all into one pressure-chamber, and then connecting the piezometer column to be observed with this still-water pressure-chamber. This plan has since been adopted by other hydraulic experimenters, has been retained for the past ten

years in the constant practice of the author, and in the construction of scores of Venturi meters, and has invariably given excellent satisfaction.

At the same time it is still true that but little positive knowledge is yet extant on the finer points of the operation or working of piezometer-tubes. Concerning the effect, if any, upon the indications of a piezometer-tube directly observed, of a current passing by, in an open channel, at right angles to such a tube, apart from the necessary effect of the current in diminishing the hydraulic level of the contained water, we have a series of most careful experiments, but that is about all we have as a test of piezometers.* In experiments Nos. 1–299 the pressure-gauge was, as a rule, attached to an equalizing pressure-chamber, formed by the hood of a shut-off gate, connected by a 6″ or 8″ pipe with the conduit under experiment. A constant effect thus produced, if any, would be eliminated, from the fact that the whole series of heights were thus observed; and any particular effect at any one station would be annulled, or else discovered, by being obliged to plot in one straight profile-line with the heights observed at the other stations of the series. In case of a rough pipe like a riveted conduit, it is plain that a single small piezometer-tube, tapped in ever so expertly and smoothed off ever so carefully on the inside, is subject to unknown disabilities, by reason of cross-currents or eddies caused by rivet-heads or laps of plates, no matter where it might penetrate the interior surface of the conduit.

*See Tr. Am. Academy of Arts and Sciences, 1878: Hiram F. Mills, "Experiments upon Piezometers."

PLATE IV.



[*Facing page* 51.]

CHAPTER VI.

THE COEFFICIENT c IN $v = c\sqrt{rs}$.

"Les formules ne sont que des outils que doit diriger l'intelligence et qui ne peuvent jamais la remplacer."—DUPUIT, *Études sur le Mouvement des Eaux* (1863), p. 228.

(Formulæ are mere tools for the intellect to make use of; they can never take its place.)

"There is no such thing in Nature; and you'll draw
A faultless monster which the world ne'er saw."
—SHEFFIELD, Duke of Buckinghamshire, 1649–1720. *Essay on Poetry.*

FOR reasons to be discussed in another chapter, the author has chosen to represent the results of the 115 experiments in form of a series of coefficients of the old-time simple formula, $v = c\sqrt{rs}$, commonly called the Chézy formula and well known in the engineering literature of Germany, France, England, and the United States. The coefficients here given could have been presented in Table I as computed for each experiment; but it has seemed more sensible and equally exact to first draw a curve of such coefficients as computed from slopes read off at regular intervals from a diagram of slopes.

Experiments Nos. 1–99 on the 48″ cylinder-joint conduit No. 1 can be resolved into three groups: the 1892 experiments, the 1896 experiments above Pompton Notch, and the 1896 experiments below Pompton Notch, as shown on Plate IV. The

TABLE II.

Conduit or Pipe.	Velocity in Feet per Second.	Coefficient.	Remarks.
No. 1, cylinder-joint, 48" diameter.	1.0	101.2	New; in 1892.
Experiments Nos. 1–99.	1.5	105.4	B.
	2.0	108.8	
	2.5	111.2	
	3.0	112.8	
	3.5	113.4	
	4.0	113.2	
	4.5	112.4	
	5.0	112.0	
	5.5	111.7	
	6.0	111.6	
Same.	1.0	78.0	Above Pompton Notch.
	1.5	84.6	4 years old.
	2.0	89.6	A.
	2.5	92.4	
	3.0	93.0	
	3.5	93.2	
	4.0	94.0	
	4.5	94.2	
	5.0	94.4	
	5.5	94.7	
	6.0	94.9	
Same.	1.0	97.2	Below Pompton Notch.
	1.5	100.8	4 years old.
	2.0	103.3	A.
	2.5	104.9	
	3.0	105.3	
	3.5	104.8	
	4.0	104.0	
	4.5	103.7	
	5.0	103.7	
	5.5	103.7	
	6.0	103.7	
36" cylinder-joint.	1.0	86.0	New; in 1892.
Experiments Nos. 100–149.	1.5	90.8	C.
	2.0	95.2	
	2.5	99.4	
	3.0	103.3	
	3.5	107.0	
	4.0	110.6	
	4.5	114.0	
	5.0	117.2	
	5.5	120.4	
	6.0	123.6	
Same.	4.93	106.3	4 years old. A.

Plate V.

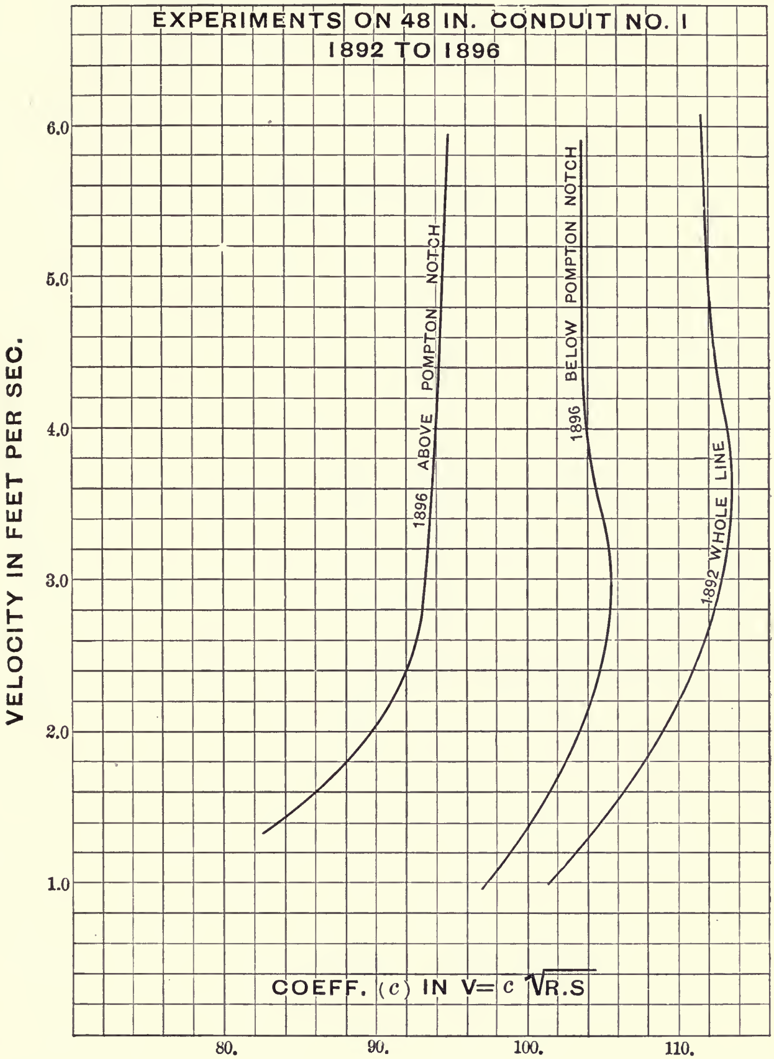


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PLATE VII.

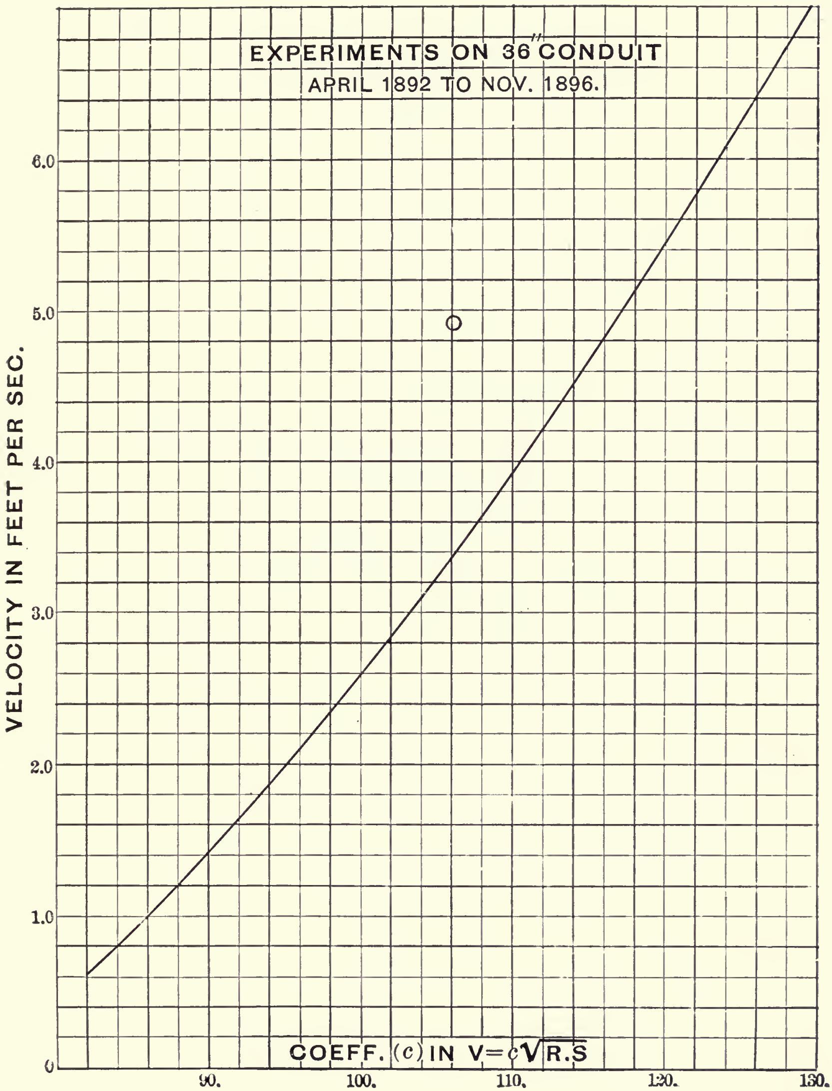

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PLATE VI.

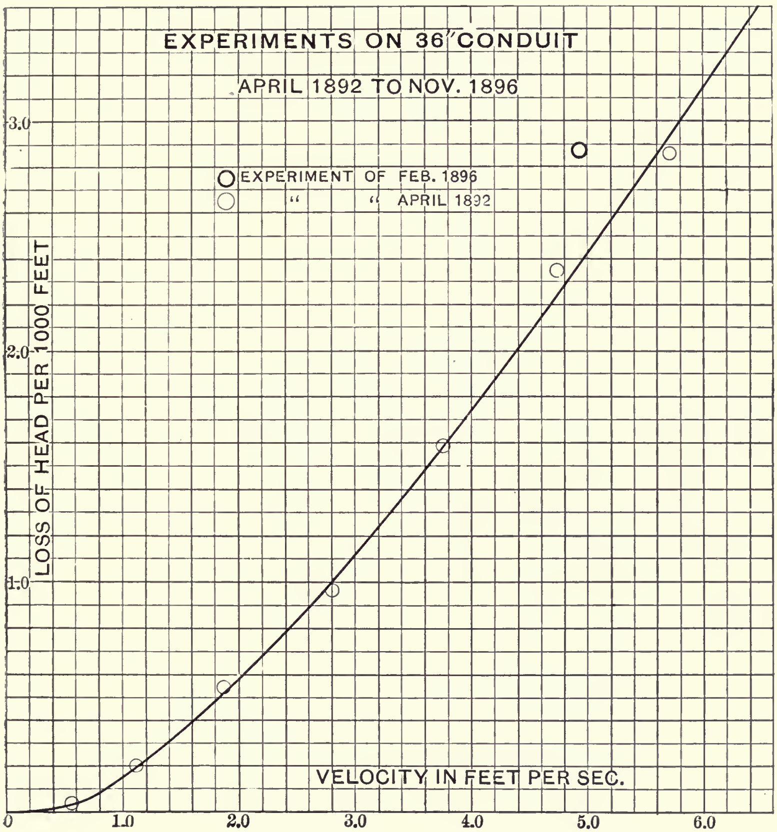

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PLATE VIII.

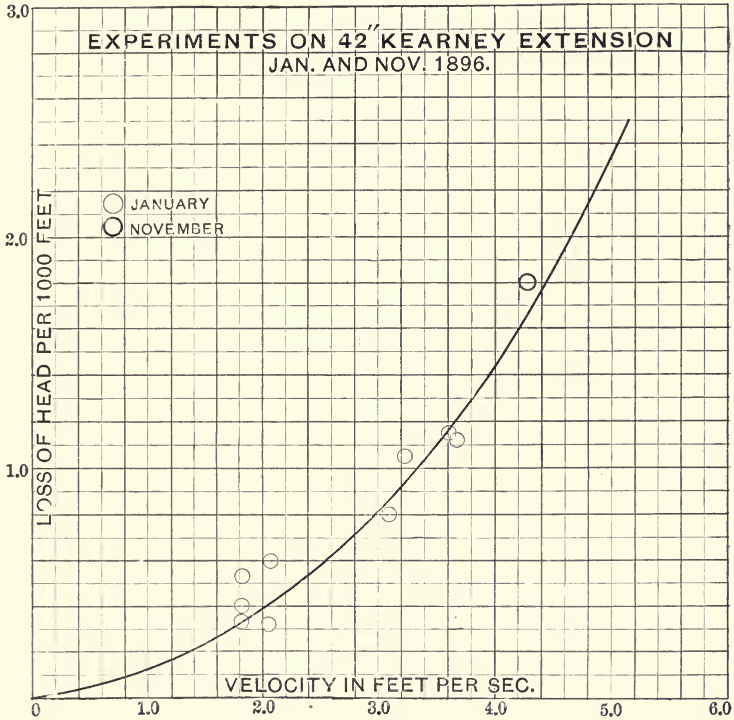

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PLATE IX.

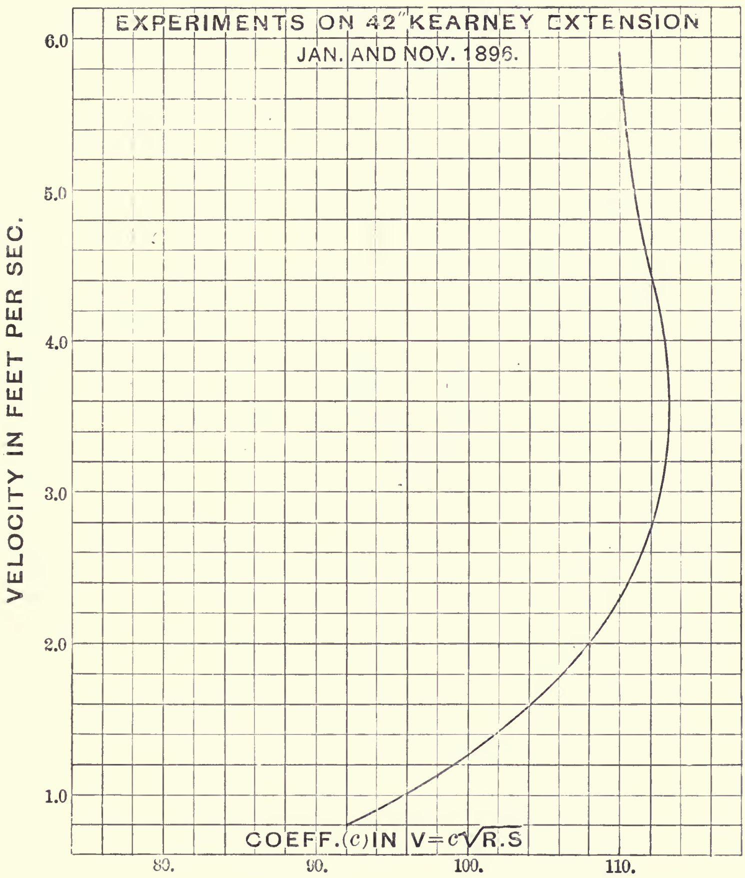

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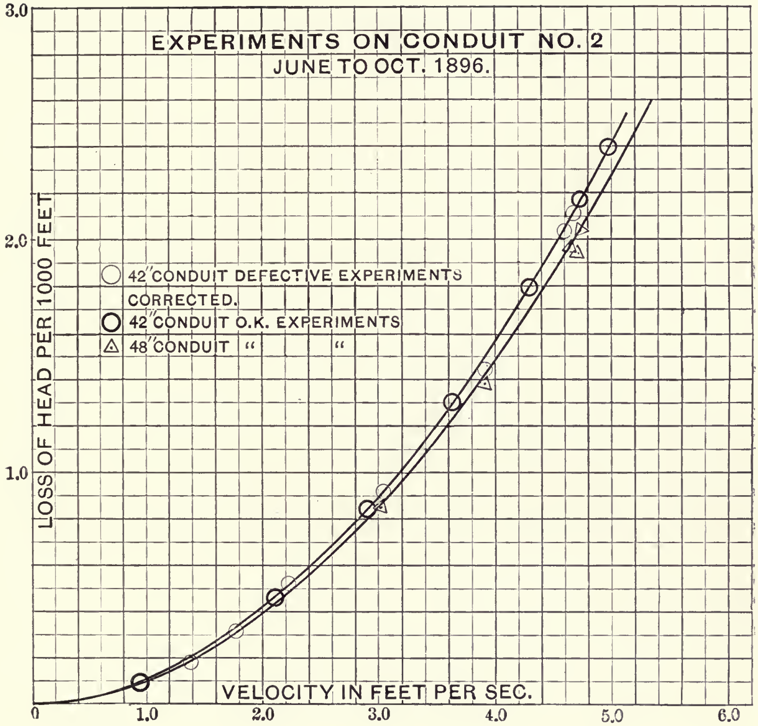
PLATE X.



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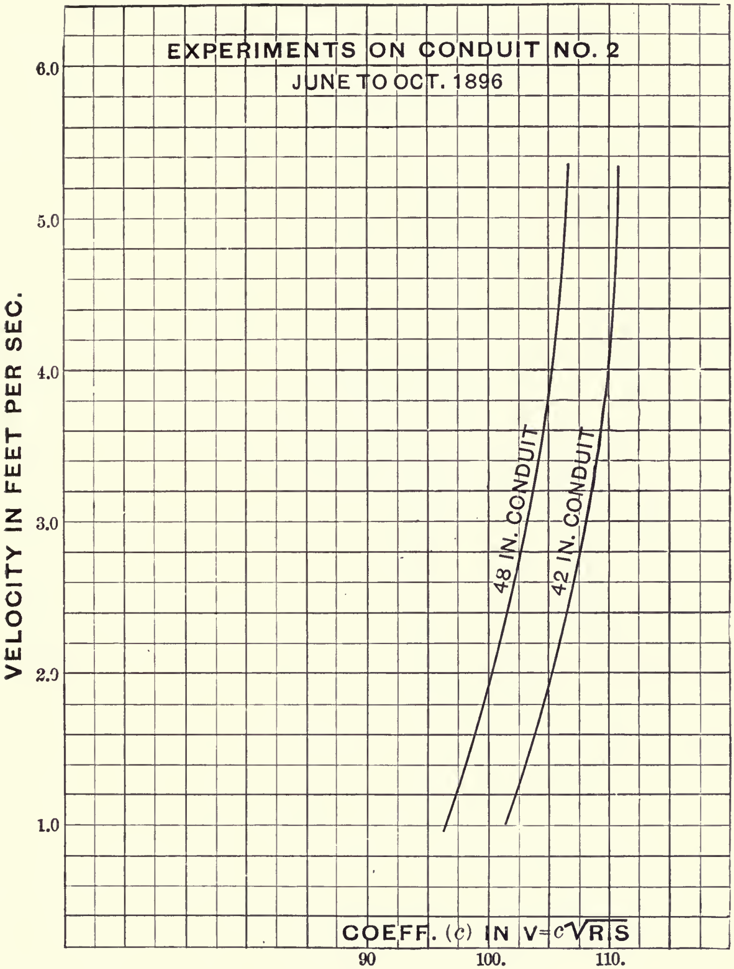

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TABLE II.—*Continued.*

Conduit or Pipe.	Velocity in Feet per Second.	Coefficient.	Remarks.
Kearney Extension, 42″, taper-joint. Experiments Nos. 150–199.	1.0	96.0	New. B +
	1.5	103.0	
	2.0	107.9	
	2.5	111.0	
	3.0	112.6	
	3.5	113.0	
	4.0	112.8	
	4.5	111.8	
	5.0	110.8	
	5.5	110.2	
	6.0	110.0	
Conduit No. 2, 48″, taper-joint. Experiments Nos. 200–249.	1.0	97.1	New. Above Pompton Notch. A.
	1.5	98.7	
	2.0	100.3	
	2.5	101.6	
	3.0	102.2	
	3.5	103.6	
	4.0	104.2	
	4.5	104.7	
	5.0	105.1	
	5.5	105.2	
	6.0	105.2 (?)	
Conduit No. 2, 42″, taper-joint. Experiments Nos. 250–299.	1.0	101.0	New. Below Pompton Notch. A.
	1.5	102.8	
	2.0	104.3	
	2.5	105.5	
	3.0	106.4	
	3.5	107.2	
	4.0	107.8	
	4.5	108.2	
	5.0	108.4	
	5.5	108.5	
	6.0	108.5 (?)	
Hamilton Smith's 11″, 13″, and 15″, taper-joint. Experiments Nos. 300–399.	4.71	107.1	New, or worn smooth by velocities up to 20 feet, and rocks and gravel passing through occasionally. B.
	6.09	110.6	
	4.59	109.4	
	6.96	113.4	
	4.38	111.6	
	6.84	117.8	
Astoria, 16″, cylinder-joint. No. 401.	4.58	110.0	New. B.

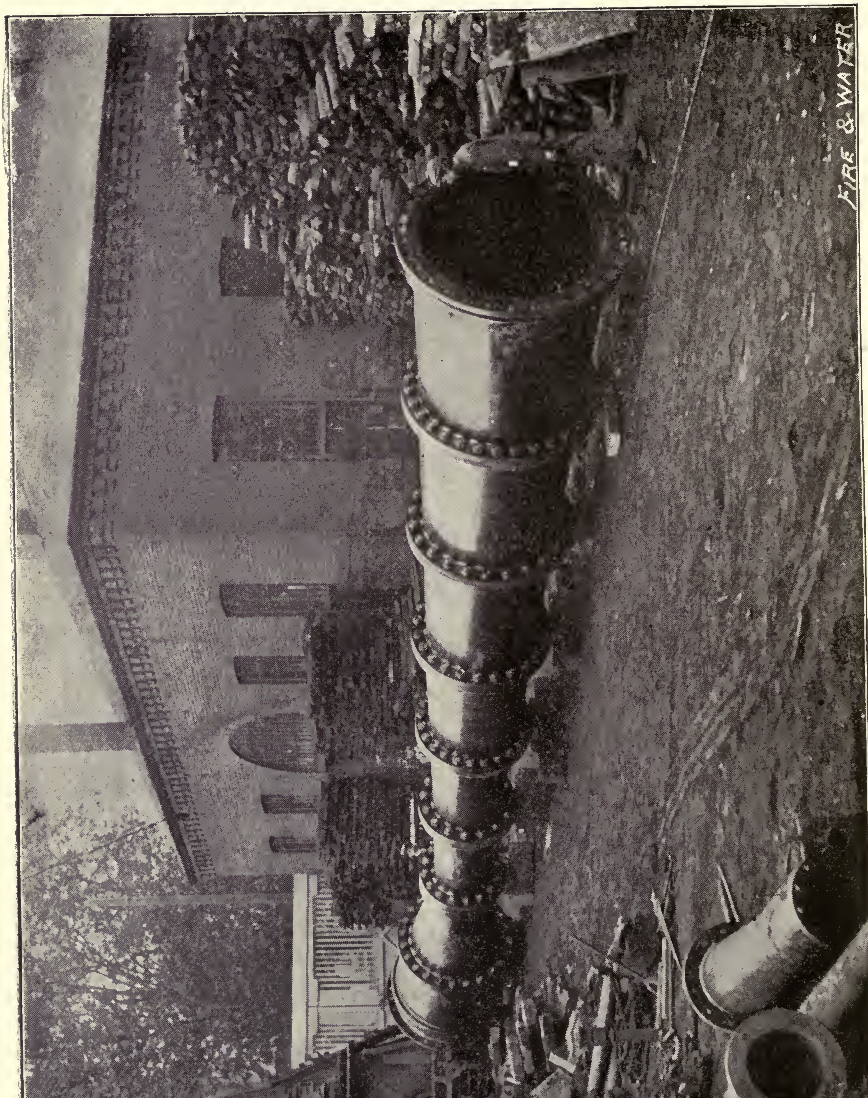
TABLE II.—*Continued.*

Conduit or Pipe.	Velocity in Feet per Second.	Coefficient.	Remarks.
Holyoke, 108″, cylinder-joints. Experiments Nos. 500–599.	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5	126.5 116.6 112.7 110.3 108.8 107.7 106.9 106.2 105.6	5 years old. B.
Darcy's 11¼″ pipe, "screw-joints." Experiments Nos. 600–699.	1.30 2.78 3.87 4.90 6.67	101.3 114.0 121.6 122.5 126.5	Presumably new. B
Rochester conduits, cylinder-joints. Experiments Nos. 700–705. 36″ pipe.	1.47 1.49	80.4 83.0	C. 14 years old. B
Same. 24″ pipe.	3.32 3.32 3.35	76.0 78.5 80.5	C. C. B.
Same. Experiments Nos. 706, 707. 38″ pipe.	3.23 3.27	114.0 116.6	New. A.
Same. Experiments Nos. 708–710. 38″ pipe on a different section than 706, 707.	3.88 3.90 3.91	109.3 109.1 109.3	New. A.

corresponding coefficients are shown on Plate V. And the table that follows gives the coefficients derived, as above stated, from all of the experiments on the conduits of the East Jersey Water Company, and those copied from literature upon the subject.

If we had ten times as many experiments on riveted conduits as are detailed in Tables I and II, some approach might possibly be made to deducing standard tables, or possibly formulæ of discharge for that class of conduits. But

PLATE XII.



60″ VENTURI METER NOW SET IN LINE OF THE ALLEGHENY CITY WATER-WORKS 60″ CONDUIT, BUILT IN 1895

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with the paucity of experiments at hand, but few permanent deductions can be drawn.

Let us hope that these experiments will give renewed encouragement to engineers to make and publish similar results of tests. If engineers will remain content at rare intervals to launch forth upon a long-suffering professional world, with much bestowal of learning and of disquisition, papers giving results that can be expressed by a single point, or perhaps two or three points, on a diagram of pipe-discharges, the art cannot make very rapid progress. But if they will elect to fit their pipe-lines with meters, so that the discharge of a conduit may be known at any instant as readily and as accurately as the discharge of a 5/8″ service pipe may now be thus known, the science of practical hydraulics will have received a great and lasting impetus; for the making of experiments on long conduits will then have been robbed of nigh all its terrors; terrors which in the past, or until quite recently, had necessarily arisen from the difficulty of metering the flow of large pipes.

The author has abundantly shown how this can be done permanently on all conduits, and at a mere nominal expense. The modern way to make conduit experiments is to place a Venturi water-meter in line of the conduit, to measure discharges. Then have a telephone-line along the pipe-line, and let the principal observer or observers carry with them so-called "test-boxes," being light, portable telephones, that can be instantly connected with the telephone-wires at any desired station along the pipe-line. One or two observers then pass along the line taking pressure-readings, while a gatekeeper at each end keeps the pressure and discharge constant. When one set of pressure-readings is com-

pleted, the telephone conveys the orders what to do next, to the two gatekeepers; and in this way a pipe line can be tested, at several velocities of flow through it, in a single day. The Venturi water-meter is therefore no doubt destined to confer large and lasting benefits on the advancement of hydraulic science, no less than on the commercial and practical management of works controlling the flow of water. And the present set of experiments may serve as an example of what it can do in contributing to the knowledge of the civil engineer, and to hydraulic science, on a subject on which but very few experiments have hitherto been extant.

Let us see whether any indications can be arrived at from the data now at hand as to the diminution in carrying capacity of riveted conduits by the lapse of time.

We have not enough experiments to determine whether conduit No. 1 had the same coefficient both above and below Pompton Notch when new. If it did, it would indicate more rapid deterioration nearer the Intake than 5 miles farther down-stream. The diminution was from, say, 112 to 93 and to 104, respectively, in four years, or from 4% to 2% per annum.

The 36″ conduit changed at one velocity from about 116.7 to 106.3 in four years, or about 2¼% per annum.

The Rochester conduit was not tested when new; but assuming that it carried about 8 million gallons in 1876, and that the coefficient of the 36″ pipe was then about 94, and of the 24″ pipe about 100, these seem to have lost about 1% and 1½% per annum, respectively, in fourteen years; though it may well be that this diminution of discharge obtained at a greater rate, say 2%, during the first five or six or more years, and then ceased. As we are at present informed, it would seem that a

diminution of 2–4% annually for five years might occur, and under some circumstances would have to be provided for. If more is to be guarded against, arrangements could be made to clean the conduit occasionally. It ought not to be very difficult to devise a brush, after the manner of what is called a "go-devil" on oil pipe-lines, and entrances and exits for it, to brush out the inner surfaces of long pipe-lines. Such a one has been devised to go through the conduits of the East Jersey Water Company, including the Venturi meters set in the line, but occasion for its use did not arise.* As we have seen, the mere running through the conduit of anchor-ice, for one or two nights, increased the coefficient of discharge about 7%.

It would be gratifying to be able to deduce from the 115 experiments the effect of the diameter, and of the method of construction of the conduits upon the coefficient, and to determine the relation between the coefficient for smooth and for riveted pipe. In the author's opinion, this cannot yet be done. To form any correct judgment in these matters would require many more experiments. It is not proposed, therefore, to do more than present some very incomplete tables and diagrams looking in those directions. It were an easy thing to take any half-dozen of the experiments and deduce from them all sorts of happy agreements with all sorts of previously published formulæ, no less than to indulge in an independent exploitation of the method of least squares, or of logarithmic homologues, and thus set up one or more new formulæ to fit these half-dozen and some other experiments, very nicely indeed; but it is more difficult, even impracticable,

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* See, on this question, Min. Proc. Inst. C. E., 1893–1894, Pt. II. 307.

to do this with 84 new experiments. In another chapter we may profitably inquire why this is so.

Comparing now the experiments on new riveted pipes with each other and with new smooth pipe as tabulated by Hamilton Smith, we get the table that follows:

TABLE III.

COEFFICIENTS FOR NEW RIVETED CONDUITS, AS DERIVED FROM THE 115 EXPERIMENTS.

Weight	B	*A*	B	A	*A*	B	A	*A*	A
Diameter	108″	*108″*	48″	48″	*48″*	42″	42″	*42″*	38″
Pipe and Joint	cyl.	*smooth*	cyl.	taper	*smooth*	taper	taper	*smooth*	cyl.
Surface	new	*new*	new	new	*new*	new	new	*new*	new
$v = 1$	(?)	*139*	101	97	*123*	96	101	*120*	...
2	...	*145*	109	100	*130*	108	104	*127*	...
3	...	*149*	113	102	*134*	113	106	*131*	115
4	...	*152*	113	104	*137*	113	108	*135*	109
5	...	....	112	105	*140*	111	108	*137*	...
6	...	....	112	105	*142*	110	108	*139*	...

Weight	C	*A*	B	*A*	B	B	B	*A*	B	B
Diameter	36″	*36″*	24″	*24″*	16″	15″	13″	*12″*	11¼″	11″
Pipe and Joint	cyl.	*smooth*	cyl.	*smooth*	cyl.	taper	taper	*smooth*	screw	taper
Surface	new	*new*	new	*new*	new	smooth	smooth	*new*	new	smooth
$v = 1$	86	*117*	(?)	*109*	...	...	...	*96*	98	...
2	95	*124*	...	*116*	...	...	...	*104*	109	...
3	103	*128*	...	*121*	...	...	...	*109*	117	...
4	111	*131*	...	*124*	...	111	108	*112*	121	...
5	117	*134*	...	*126*	110	113	110	*114*	124	108
6	124	*136*	...	*129*	...	116	112	*116*	126	110

The first strange result portrayed in Table III is the fact that a 48″ taper-joint pipe should at times have a smaller coefficient than a 48″ cylinder-joint pipe. The author can suggest no explanation, except it be a difference in smoothness of the asphalt dip, so much in favor of conduit No. 1, as to more than outweigh the advantages of the taper-joint. It is a historical fact that 48″ conduit No. 2 was dipped in the winter, for cold-weather work, but remained uncovered during some very warm days, causing a modified form of stalactites of asphalt to form in the interior. A similar explanation is suggested to account for the difference in the two 42″ taper-joint pipes. Kearney Extension pipe had a smoother asphalt dip than any of the other conduits. The two prints showing the interior of conduit No. 2 exhibit the wrinkles of asphalt frequently found in lines of pipe. Kearney Extension 42″ had a smoother coating of asphalt than conduit No. 2; and the upper end of conduit No. 1 was smoother than the 48″ section of conduit No. 2. Neither the Darcy 11¼″ pipe nor the 36″ pipe coefficients conform in variation with the different velocities through them to the rest of the table. Both increase decidedly with an increase of velocity, while the other pipes show no marked increase of this sort.

No deduction at all can be drawn from the table as to the effect of the diameter on the coefficient.

The figures in small italics refer to the coefficient for smooth pipes of the same diameter, as deduced by Hamilton Smith, p. 271 of "Hydraulics," from the best experiments extant on such pipes. The difference between the letter-press figures and those in italics should indicate the effect of

roughness of interior produced by the laps of plates and rivet-heads.

It will be noted as a remarkable exhibit that this difference increases with the diameter. This accounts largely for the insistence of some engineers that riveted pipe have as good a carrying capacity as new cast-iron pipe, while this is by no means true for large diameters. Engineers who have stated and insisted as above have formed their opinions wholly from a consideration of riveted pipes less than 18″ in diameter, or else have been influenced by the reported "fake" gaugings of the Rochester 36″ and 24″ conduit.

The table below will be readily understood from the explanations given for Table III.

Table IV.

COEFFICIENTS FOR OLD, RIVETED CONDUITS, AS DERIVED FROM THE 115 EXPERIMENTS.

Weight	B	*A*	A	A	*A*	C	B	*A*	B	*A*
Diameter	108″	*108″*	48″	48″	*48″*	36″	36″	*36″*	24″	*24″*
Pipe and Joint	cyl.	*smooth*	cyl.	cyl.	*smooth*	cyl.	cyl.	*smooth*	cyl.	*smooth*
Surface	5 years old	*new*	4 years old	4 years old	*new*	4 yrs old	14 years old	*new*	14 years old	*new*
$v = 1$	117	*139*	97	78	*123*	...		*117*	..	*109*
2	110	*145*	103	90	*130*	...	83	*124*	..	*116*
3	108	*149*	105	93	*134*	...	(for v	*128*	80	*121*
4	106	*152*	104	94	*137*	...	$= 1.5$)	*131*	..	*124*
5	...	....	104	94	*140*	106		*134*	..	*126*
6	...	....	104	95	*142*	...		*136*	..	*129*

CHAPTER VII.

$v =$ TABULATED $c \times \sqrt{rs}$.

"If *this* be treason, make the most of it."
—PATRICK HENRY, 1765.

"Difficult, I say, for the truth is, these knowledges, though of things next our senses, are sometimes more abstruse and hidden than the knowledge of things more remote; and much better, and with greater exquisiteness are known the motions of the Planets, and Periods of the stars, than those of Rivers and Seas; as that singular light of Philosophie of our times, and my master, Signore Galileo Galilei wisely observeth in his book concerning the Solar spots." *

—In THOS. SALLUSBURY'S *Mathematical Collections*, 1661: Castelli, "On the Measurement of Running Water," 1628.

ALTHOUGH the author has declined to evolve a formula or otherwise to attempt to determine and portray, from an analysis of the 115 experiments at hand, the complex law, if such it may be called, governing the flow of water in riveted conduits, it may be proper, nevertheless, to add a few reflections upon, and a brief historical sketch of, the studies that have been made concerning the relation between the mean

* Istoria e Dimostrazioni intorno alle Macchie Solari e loro accidenti comprese in tre lettere scritte al Sig. Marco Velsero da Galileo Galilei, 1613.

This saying of Galileo is also quoted in "Abhandlung von der Geschwindigkeit des fliessenden Wassers," etc. (Brünings, tr. by Kröncke, Frankfurt a. M., 1789).

velocity of water flowing in a pipe, and the cross-section and slope of the pipe.

Again are we confronted with the saying of Galileo more than 250 years ago, above quoted. True at the birth of hydraulic science, when these words were spoken, they are almost equally true to-day.

When the Academy of Sciences of Berlin offered a prize, in 1750, for the solution of the problem: to state the relation between the mean velocity of a canal or river and its slope and cross-section, the celebrated d'Alembert declared that he, for one, did not think he had the requisite powers of analysis nor the endurance or courage to undertake the solution of such a problem in the term of a few years.* Nor has any mathematician ever done more than attempt to solve a modified problem of this sort, as for instance the celebrated Euler, who treated it on the supposition that all the particles move in right lines.†

Experimenters who have evolved formulæ have followed a similar routine down to the present day. They first endow flowing water with attributes which it does not possess, and then proceed to torture the few experiments they may have made, or may collect, into the straight-jacket of a formula which is based upon those non-existent attributes of water. Or else they use the milder coercion of marshalling the few called and chosen experiments, willy-nilly, by the gentler per-

* Essai d'une nouvelle théorie de la résistance des fluides (Paris, 1752); Introduction, p. 29.

† "Principes généraux du mouvement des fluides" (Berlin Academy, 1755); and the 1770 volume of the Commentaries of the Petersburg Academy, in Latin; German translation by Prof. Brandes (Leipzig, 1805), "Die Gesetze des Gleichgewichts, und der Bewegung flüssiger Körper."

suasion of the method of least squares, into the framework of some formula of resultant outlandish mien; or, as the very latest method, by the use of logarithmic homologues. The climax of this sort of work has probably been reached by the labors of Ganguillet and Kutter,* and a reaction may now, in the author's opinion, confidently be expected to set in.

The lines of procedure upon which the thoughts of all hydraulicians for the past 150 years seem to have been fixedly set are probably nowhere more radically stated than in the following, culled from Weisbach's "Experimental-Hydraulik" (Freiberg, 1855): "§ 22. *The Cohesion and Resistance to Friction of Water in Pipes.*—Water does not flow past all points of one and the same cross-section of a pipe with one and the same velocity, but, on the contrary, the particles which flow nearest the surface of the pipe have a less, and those more distant from this surface have a greater, velocity." We may profitably stop here to interject that, as may presently appear, both the cohesion and the resistance to friction of water, as it flows in pipes of the sizes ordinarily used, are so small that, in comparison to other disturbing causes, they do not have a ruling effect; and that practically all the particles of water in a cross-section of measurable thickness, say as contained in a length of pipe equal to half the diameter, do flow past a given point with one and the same effective velocity in the direction of flow. But a hydraulician seems to be lost to truth and to the search for truth so soon as he has made the false beginning for his studies above quoted. Once possessed with the fever for formulæ, his common sense seems to forsake him. But for

* "Flow of Water in Rivers and other Channels," Hering and Trautwine (N. Y., 1889, John Wiley & Sons).

150 years have they all spoken as above, and even when they have recognized and stated that eddy, circular, spiral, and similar motions of the particles of water have a great influence on the mean velocity in the pipe, they have universally lacked the courage of their half-stated convictions, and, satisfied with such a bare half-statement, have gone on to compute, as theretofore, wholly on the basis of the false assumptions already quoted. Of all the writers, possibly approaching a hundred, in French, German, and English, known to the author, he recalls one only, Dupuit, who, in his 1865 edition of "Études théoriques et pratiques sur le mouvement des eaux courantes," has spoken fearlessly upon this phase of the question.

But let us continue to explore the beaten track. Says Weisbach, following the quotation just given: "This variation in the velocity of efflux past one and the same plane of cross-section has its cause in the cohesion of the water *per se* and in its adhesion to the pipe surface. The body of water contained in the pipe may be likened to the trunk of a tree: just as such a tree-trunk is composed of annually accumulated layers, the one within the other, so is the water flowing in a pipe composed of a lot of hollow tubes, which similarly surround and contain each other. The outer one of these water-tubes is in contact with the interior surface of the pipe, and is totally prevented from moving by reason of the attraction between the two, and the rest of these tubes stick together by means of cohesion or agglutination, so that no one can move without affecting the rate of motion of the others. In consequence of this we find that the water-tube which is next the tube which adheres to the pipe can move along but very slowly, while the third water-tube can move faster, the fourth still

faster, etc., etc. We find, therefore, that the body of water flowing in a pipe consists of concentric tubes, each outer one enveloping the one next within, which move at different velocities, the one sliding over the next one, in such manner as to cause the innermost cylindrical or prismatic kernel to have the greatest velocity and the other concentric layers to have the less velocity the farther they are from the centre, or the nearer they are to the interior surface of the pipe." All of which may be an excellent description of the way cold molasses or coal-tar dribbles along through a pipe, but certainly does not apply to water.

It is true that Weisbach goes on to say that in smooth pipes the material of which they are composed is of no consequence as far as the velocity of the contained water is concerned; and in rough pipes eddies are formed, which naturally increase with the dimensions of the protuberances or depressions. "But," says he "we will in the future always assume a perfectly smooth interior surface of the pipe, and need therefore take no further notice of the material differences in these pipe interiors." Or, in other words, the pipes he considers are a kind of pipes not met with in practice; and as for those met with in practice, they need be no further considered.

Only in recent years has it at length been recognized that even in the smoothest of pipes—such as of drawn glass, for instance—eddies and a spiral or vortex motion of flowing water will take place so soon as a certain small critical velocity is exceeded; and that they are generally present in the practical application of the principles of hydrodynamics now under consideration; to which the author now begs to add

that, in his present judgment, these disturbances of rectilineal flow are of overruling importance in the study of the carrying capacity of pipes, and in comparison with them considerations of varying velocity at different points in the plane of a cross-section, or of cohesion, of agglutination, or of "friction," in the practice of the civil engineer, must be relegated into decidedly subordinate positions.

Thus Hagen, one of the most outspoken, clearest intellects that ever graced the profession of the civil engineer, in his "Untersuchungen über die Gleichförmige Bewegung des Wassers" (Berlin, 1876), and in his "Handbuch der Wasserbaukunst" (Berlin, 1869), vol. I. p. 169, repeatedly calls attention to the commotion to be observed in water flowing in smooth experimental channels, or through glass tubes, by mixing sawdust or amber-dust with the water; and to the fact that there can therefore be no assumption of rectilineal motion in any ordinary water-channel. Finally, Prof. Osborne Reynolds, in Trans. of the Royal Society, 1883, demonstrated the fact of a critical velocity in pipes, below which right-line motion might be assumed, but above which it became absurd to assume it, and showed that in fact it existed in scarcely any of the cases with which the civil engineer, that is to say, the reader for whose consideration this is written, has to deal. Notwithstanding all this, even these two experimenters have gone on, hoping against hope, and have endeavored to evolve some simple law for the velocity of water flowing through a pipe.

Most computers of formulæ for the flow of water in pipes have assumed, or constructed, a certain general form of formula, and have then confined their computations to the

determination of one or more coefficients believed to be constant. Their general form has been founded, or has been thought by its makers to be founded, on sound reasoning, in itself based, however, on certain hydraulic assumptions; but good writers like Merriman * or Ritter † have not hesitated, nevertheless, to call these formulæ empirical.

Thus the form of the Chézy monomial formula, and of Prony's or more properly Girard's binomial formula, are each founded on reasoning based, the one upon an assumed mode of motion of the water in the pipe,‡ the other upon a consideration of the results of experiments by Coulomb on the resistance of water to bodies passing over or through it, which was then supposed to be an analogous case to that of the body, the pipe, standing still, and the water moving.§ And the host of writers who have accepted either of these forms of formula have for the greater part confined their attention to evolving laws of variation of the one or two coefficients included in the formulæ. But no refinement of its coefficient, or of laws of the variation of such a coefficient, even if they could be found, will ever convert an empirical formula into an expression of natural law. Wherefore, recognizing the empirical nature of the Chézy and of the Girard form of formula, and recognizing the futility of all attempts at a determination of a law to express the variation of the

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* Merriman's "A Treatise on Hydraulics" (N. Y., 1895), p. 217.

† Ritter, "Lehrbuch d. Ingenieur-Mechanik" (Hanover, 1876), p. 481.

‡ See P. S. Girard, "Rapport sur le Projet Générale du Canal de l'Ourcq" (1803), p. 33; or Hagen, "Untersuchungen," etc. (Berlin, 1876), p. 89; or Merriman's "A Treatise on Hydraulics" (N. Y., 1895), p. 215.

§ See P. S. Girard in "Mém. de l'Institut de France," 1813, 1814, and 1815. p. 253. Also claimed as Girard's invention, in the 1803 Rapport, and so admitted by Prony and others.

coefficients contained in these formulæ, other writers have attempted by the method of least squares to discover other forms of formula; fine examples of which kind of work may be seen in the writings of Hagen, and of Prof. Unwin,* already referred to.

Notwithstanding all this work, very little has been accomplished towards ascertaining any law of flowing water, properly so named, in the 150 years of experiment and study since 1750, whether the investigations be confined to pipes or extended to open channels and rivers as well. We have experiments ranging from those on the flow through pipes 1/8 in. and less in diameter, up to gaugings of the Amazon and of the Mississippi, but all classes of channels elude conformity to a recognizable law of flow.

Those on exceedingly small pipes, or on very slow velocities in larger channels, more nearly disclose a regular mode of motion, as might be expected; and it is found, may be represented by a formula of the following form:

$$v = crs;$$

while the Chézy form is

$$v = c\sqrt{rs};$$

and the Girard form,

$$av + bv^2 = rs;$$

and other tested forms are:

$$av^x = rs,$$

$$av = r^x s^y,$$

$$av^x + bv^y = rs,$$

* See article in "Industries" (Manchester, 1886), by Prof. W. C. Unwin.

$$\left(a + \frac{b}{d}\right)\frac{v^2}{2g} = rs, \qquad \text{(Darcy form.)}$$

$$\frac{av^x}{d^y} = s,$$

$$c\frac{v^x}{d^{3-x}} = s. \quad \left\{ \begin{array}{l} \text{(Prof. Reynolds' form,} \\ \text{omitting the term to} \\ \text{denote effect of temper} \\ \text{ature.)} \end{array} \right.$$

In all of which a, b, and c are coefficients;

v is the mean velocity;

s is the fall, divided by the length, or the slope;

r is the area divided by the wetted perimeter;

d is the diameter of the pipe; and

x and y are indices to be determined from the results of experiments.

As before stated, the climax of striving for a law and swallowing a monstrosity is perhaps reached when it is supposed that empiricism can gain anything by the use of a formula, or that nature can be observed to work according to a law, whose expression is, that

$$v = \frac{a + \frac{b}{\omega} + \frac{c}{s}}{1 + \frac{\omega}{\sqrt{r}}\left(a + \frac{c}{s}\right)}\sqrt{rs}; \text{ the Kutter formula,}$$

in which, after all, the coefficient is not a constant, nor a variable of r or of s, but must be given one of eleven values depending on the estimated rugosity of the channel.

The extent to which the worship of such false idols and the hope of salvation through formulæ can go is perhaps best illustrated by this extract relating to their use:

"At first, the authors of the Kutter formula divided all possible cases into classes or categories (as did Darcy and Bazin), and suggested six different values for the coefficient of roughness n, beginning with smooth cement or planed boards, and ending with streams the beds of which were covered with detritus and aquatic plants. Later these six classes were given up. The advantages of this new formula were quickly grasped by the engineering profession, and it gradually supplanted the old formulas for general use.

"In recent years, however, through the further development of engineering science, the demand for greater refinements, for greater economy in getting better results with less expenditure of money, has put the Kutter formula in a similar position to that occupied by the Chézy formula thirty years ago. The coefficient n, which was first considered to be a constant quantity, and which roughly can be considered as such, is also found to vary, though between much smaller limits than the original coefficient c.

"To illustrate this statement by the simile of a decimal fraction, suppose the Chézy formula gave results that could safely be expressed by units only, the greater refinement of the Kutter formula gave results which could be safely expressed in tenths of a unit. At the present time we seem to be in need of a formula which will give us safe results in hundredths of a unit. Gaugings are being made with greater precision. It is more necessary to-day that watercourses and pipe-lines should give the greatest discharges with the

least possible outlay of money. Works built in recent years on the assumption (continuing to use the above simile) that accuracy up to tenths of a unit was sufficient, have in more than one case disastrously affected invested capital."

Invested capital, and capital about to be invested, is no doubt exposed to many vicissitudes, hence is proverbially fearful and on guard. But it can take care of hostile designs upon it, if it be not led astray by volunteer friendship's offerings such as these.

None of the formulæ above written, or forms of formulæ, have been found satisfactory. None represent, or can by twist and turn of coefficients or of indices be made safely to represent the cases of flow for which they were designed. They will serve and can be made to fit a few cases, but multiplication of experiments invariably leaves the formula incompetent to represent the variations shown by experiment.*

But out of all this turmoil and crash of worlds of computation has remained, with perhaps least tarnished of reputations, because of modest demeanor and pretensions, and as

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* See Unwin's article in "Industries" (Manchester, 1886); or the present author, in Tr. Am. Soc. C. E., July 1896, p. 298, which shows that ω, or rugosity, in the Kutter formula would be given widely different values in the same pipe by using experiments at one or another velocity in the same pipe to compute it,—a veritable *reductio ad absurdum*.

See many others, almost all articles on the flow of water in pipes or in canals, to the same general effect. Some excellent work exposing the falsity of the assumptions on which these formulæ are founded, and their consequent failure to portray the discharge of large rivers, may be read in Tr. Am. Soc. C. E., Nov. 1895, p. 347, the magnificent article by Wm. Starling, M. Am. Soc. C. E., on "The Discharge of the Mississippi River." See also the discussion on this paper, notably that of C. McD. Townsend, M. Am. Soc. C. E., in the same Transactions, July 1896, p. 336.

a convenience in the classification of results, if good for nothing else, the generally accepted Chézy formula—a sort of survival of the fittest. Of course its coefficient must have a wide range of values to cause it to be applicable to the many cases in which engineers have occasion to use it; and it is also beginning to be recognized that every engineer had better find out from experiment his own particular quota of coefficients, applicable to his own particular cases. Nor need he bother himself to go further and attempt to evolve a law of variation for the coefficients themselves. It does not make the computed coefficients any clearer or easier of use to hide them under the form of the unknown quantity of an additional formula. Better it is to let them remain in the light of day, without change, other than to have them properly arranged and marshalled in the ranks of a well-designed table.

On account of such thoughts as these the author has chosen to represent the results of the 115 experiments in form of two tables of coefficients appurtenant to the Chézy formula.

It is a singular circumstance that the origin of two of the best-known empirical formulæ used by civil engineers should be so shrouded in mystery as is that of the Chézy formula for the flow of water in channels and that of the Gordon formula for the strength of columns.

To state who Gordon was, and to give the origin and first appearance in print of the Gordon formula, would form a fitting prize problem for engineering students.

As regards the history of the Chézy formula, research shows it to be quite interesting.

It is found in an embryonic condition in a book by Albert Brahms on "Dike and other Hydraulic Constructions," of which the preface is dated 1757, though some of the plates are dated as early as 1753. Brahms seems to have been a country surveyor in one of the small German principalities of his time, spurred on, perhaps, to the work under consideration, by the prize offered by the Berlin Academy in 1750, above referred to. He explains that while a sphere placed on an inclined plane would move with constantly accelerated velocity, water flowing in an inclined channel moves with a uniform velocity, because the resistances counterbalance the acceleration. He also says that the velocities are as the square roots of the slopes, and that "the values of friction at equal slopes of water surface are to each other, in case of open flowing waters, as the areas wetted by the water are to the quantities that flow over them." He also gives the depths, velocity, and slopes of two rivers, so that Hagen * is enabled to compute in 1876 that Brahms meant that

$$v = 97.6 \sqrt{rs}.$$

Brahms himself does not give any formula.

In 1769 Perronet and Chézy were appointed to report on the proposed Canal de l'Yvette, projected to bring water into Paris; and in 1775 Chézy made a report on this canal, which he addressed to Perronet, and which has never been printed, but was deposited with the manuscript collection of the École des Ponts et Chaussées.†

This report is said to contain the original Chézy formula.

* "Untersuchungen," etc. (Berlin, 1876).

† Girard, "Rapport sur le Projet Générale du Canal de l'Ourcq," 1803, p. 33. Also, Prony, "Récherches Physico-Mathématiques" (1804), p. iv.

Girard states it twice—once in the "Rapport" already referred to, when the conclusion reached is that the velocities are proportional to $\sqrt{s}$; and again in "Mém. de l'Institut de France" (1813, 1814, and 1815), p. 251, when he gives it as $sa = cpv^2$, or $v = c\sqrt{rs}$. Girard also states that Bossut applied the Chézy formula to the flow of water in pipes, though Bossut * does not appear to have given Chézy any credit for his formula. In fact Girard and many others of those times do not value it, but think more of the binomial form, derived by Girard from the experiments of Coulomb on the friction of bodies over or through water. But Eytelwein,† the great German hydraulician, placed himself on the side of the Chézy form of formula, so that to this day it is called in Germany the Chézy-Eytelwein formula, and of late years it has become popular, and is known as the Chézy formula in France, England, and America.‡

A comprehensive view of this whole subject can only be got from the joint experience of experiments conducted, and of many books read. It does not yield either to the treatment of the student and votary of book lore, nor to the contracted view of the reader of only one book. To those fitted by experience, it is submitted that no form of formula yet proposed for the discharge of water flowing in a pipe or channel properly approximates to the results of nature or of experiment.

The reason why these 150 years of the world's work on these lines has been so fruitless of proper results is, in the

* Bossut, "Traité Théorique et Expérimental d'Hydrodynamique," (Paris, 1795), vol. II. p. 143.

† "Handbuch der Mechanik und Hydraulik" (Berlin, 1801).

‡ See Note D.

PORTRAIT OF CHÉZY, FROM BIOGRAPHIE CHÂLONNAISE, D'AMÉDÉE LHOTE.

[*Facing page* 74.]

author's opinion, not far to seek. As no stream can rise above its source, so no formula founded on error can hope to attain truthful results. Nearly all work done to date has been based on considerations of friction, or of resistances to sliding motion, viscosity, etc. It is now submitted to the profession, and to savants as well, that the time has come when the stone which was rejected of the builders should become the head of the corner. These vortex and other circular or spiral motions in flowing water are presented, not exactly as the chief resistances to, but say diversions from or annulments of, the action of gravity in the case of flowing water. We can gain an idea of them by watching the action of small particles contained in flowing water and of the same specific gravity, or of coloring matter injected into water, or of clouds of dust carried along in air-currents. A single particle, or a whirl of particles, of water strikes the side or bottom of the channel, is reflected, as a billiard-ball is reflected from its cushion, perhaps crosses over, is reflected again, and in this way the whirl or the particle moves at an unknown velocity in the direction of the axis of the channel. All this has been said scores of times, but following it, the routine method of thought has nevertheless been pursued in a vain attempt to get truth out of error, figs from thistles, a true formula out of the false assumption of mere frictional resistances to flow.

Let us be honest enough to acknowledge that these irregular vortex and eddying motions in and of flowing water are ordinarily its principal features, and that their general determination or evaluation in a formula is beyond human power. In other words, let the word be uttered: There is

no law of water flowing in pipes and other channels, be they ever so smooth, that can be expressed in a simple relation between slope, cross-section, and mean velocity. Also, if there were such a law for smooth pipes and channels, it would be nigh useless in the practice of the civil engineer, who is forced to deal with channels as they become affected by accumulated slime, rust, tubercles, etc. Such a law may exist for the case of minute threads of water issuing at high pressures, or for extremely slow velocities in such capillary and other channels; but as soon as straight-line motion has ceased we practically enter the domain of chance as represented by the law of averages. Undoubtedly chance itself is subject to law; but to get a formula to represent such a law of averages—the average retardation caused by convolutions, interaction, and reflection from the sides and bottom of the channel, of whirls and of vortexes of water—we would have to invoke the aid of the laws of probability, not of the principles of mechanics.

This is what the author said in his original paper on the Venturi Water-meter, Tr. Am. Soc. C. E., Nov. 1887:

"The reason, I will suggest, why the coefficients belonging to this form of gauging apparatus are so nearly uniform is largely on account of the close similarity between the conditions assumed by theory and those found in actual practice, regarding now the state of the liquid as it passes through the venturi. Here, if anywhere, water may be supposed to flow as though composed of the traditional 'filaments' of the school-books; while the bubblings of a boiling, seething caldron are but little more violent and irregular than the motions of the alleged 'threads' of water, as we find that

water in ordinary practice, and as it flows in canals, or even in the ordinary line of pipes, or in tubes."

That is to say, even in new, smooth channels is this failure to conform to straight-line motion, or to the laws of mechanics, made manifest. We are first called upon to surrender knowledge of what takes place in channels as they appear in use, and in the condition in which their behavior has practical value, so as to compare them when they are all new and smooth, only to observe that, even when thus new and smooth, motion through them is so irregular that it will not submit to computation by ordinary laws or formulæ.

A striking example of this is furnished by a comparison of the discharge of the Sudbury Conduit supplying Boston, and that of the last-built Croton Conduit, supplying the city of New York. These two works were built under practically identical leadership, and under precisely similar circumstances and conditions, the one immediately after the other. The same engineers, the same class of materials, identical methods of construction, distinguish them. Most excellently conducted gaugings or experiments of discharge were made upon the Sudbury Conduit, and its formula of discharge was computed when it was new. Yet when such measurements were repeated on the newly completed Croton Conduit, only 94.5% of the expected results were attained.*

One of the grossest errors in the consideration of flowing water has been the weight given to the so-called scale of velocities extending from the bottom or sides to the thread of the

* See Reports of Aqueduct Commissioners, Croton Aqueduct, 1887 to 1895, p. 101; also "The Water-supply of the City of New York," by Edward Wegmann (John Wiley & Sons, N. Y., 1895).

current in the case of open channels, from the exterior circumference to the centre, in the case of pipes. Even graphical analysis has in this instance contributed to a spread of error. The regular way has been to draw such a scale of velocities, say a parabola, showing, as indicated by some form of current-meter which measures and records only linear motion in the direction of the axis of the channel, the axial length passed over by a point in an alleged "filament" of water in one second of time. This diagram looks handsome enough, and is deemed satisfactory as demonstrating that water moves in lines and faster at the top than at the bottom, etc., etc. But suppose one were to continue the graphical representation thus begun, and show where the several points in the first-second-of-time parabola would be at the close of the second second, at the close of the third second, in a minute, in a quarter of an hour, or still later. Would there not result a most astonishing diagram of the positions, at the close of some measurable period of time, of the original particles erst strung along the correct parabola? Would it not teach everybody what nonsense it is to suppose such a form of motion in flowing water for an instant; to make of it the basis of reasoning and of computation; and that water in truth has nothing in common with such hideous suppositions?

Now let us examine in the light of an experiment fortunately at hand what really takes place under such circumstances.

In the December, 1893 number of the Tr. Am. Soc. C. E. is an article by G. H. Benzenberg, M. Am. Soc. C. E., on the "Sewerage System of Milwaukee and the Milwaukee River Flushing Works." This able engineer,

after completing the discharge-sewer 12 ft. in diameter and 2534 ft. long, for the latter-described works, was anxious to know its volume of discharge under various conditions. As both ends of it are submerged, he hit upon the expedient of measuring the velocity of the water through it by injecting suddenly two ounces of red eosine, dissolved in one quart of water, into the sewer at one end, and noting the discharge of this colored water half a mile farther down-stream. He was enabled to do this with accuracy, because "the color was readily perceptible at the outlet, and was never distributed over a length of more than 7 to 9 ft., being about 1/3 of 1% of the length of the tunnel, the centre of which was taken as the point observed. The compactness of the coloring matter showed that the velocity was practically uniform at all points in the cross-section of the tunnel, which again in itself was very uniform throughout the entire length of the tunnel." Nevertheless, a 4″ × 6″ block 18 in. long was found spiked to the interior on inspection of the tunnel the next spring.

Let us add that in these ten experiments of discharge the mean velocity ranged from 3.9 to 6.9 ft., and, that nothing might be lacking to prove the ordinary conditions of flow, that the computed coefficient in $v = c\sqrt{rs}$ ranged, with the velocity, from 122.7 to 137.3. Here we have the truth about flowing water, and a truthful representation of how it flows. A body of it equal in length to, say, half the diameter of the pipe stays together, though riddled and seething with internal motion, for the distance of half a mile, or for from 6 minutes 4 seconds to 10 minutes 52 seconds, and no doubt for a much longer space and time in actual practice in straight channels. Where now is the "scale of velocities"?

Where the " filaments," and their " friction " among themselves and against the interior of the conduit? What becomes of all the formulæ based on the existence of such a scale and such friction and filaments ? Let us answer truthfully: They are left without a reason for their existence, except as one of the simplest of the lot of formulæ may serve as an aid in the classification and the orderly arrangement of experiments, or of gaugings, that have been made in the past, or are yet to be made.

To some this may seem a negative result. To the author it appears like positive and necessary action in clearing the ground of a mass of encumbering obstacles, preparatory for new studies, for new work, and for true progress, in the art of the civil engineer.

APPENDIX.

NOTE A.

It is customary to call an engineer engaged in this manner by a corporation a Consulting Engineer, and his knowledge is supposed to be, and his rank is then generally considered, above that of the Chief Engineer of the corporation. It is true that in this case Mr. Kuichling was engaged at the sole instance of the Chief Engineer, and for the one special purpose that has been named; but Mr. Kuichling never was an Assistant Engineer, as that term is used and understood, and as some have supposed. He was always paid, to illustrate, on bills made out by him for a certain number of detached days' service, many of them in his own office in Rochester, N. Y., and for his travelling expenses. His first bill was paid Oct. 1889, the last was for services rendered up to Aug. 14, 1890, and he never appeared on the pay-rolls of the company, on which were paid the "Principal Assistant Engineer," the "Second Assistant Engineer," and all the other Assistant Engineers. And it may be said at once that there is no occasion for any one to plead the "baby-act" in Mr. Kuichling's behalf, in the matter of anything he did in computing

the carrying capacity of the East Jersey Conduit of 1889, as there might be had Mr. Kuichling been an ordinary Assistant Engineer employed upon the work. He was offered such a position in the summer of 1890, shortly before accepting that of Chief Engineer of the Rochester Water-works, and, to accept the latter, declined it. The author has said elsewhere that with apparently more than usual prudence, and as a safeguard in a novel work and undertaking, he had engaged Mr. Kuichling to be his " principal assistant in the design of the Newark conduit "; and the phrase has perhaps pardonably led to misconception as to the professional relations of the parties, which were not under discussion when the quoted statement was written, and therefore those relations were not then described with especial care or precision. The above are some of the facts in the case, and others will follow.

NOTE B.

In a report made to his company, but which was widely published in January 1896, the author said: "Among them (engineers and writers who had been deceived by the Rochester report) I could name Hamilton Smith, Jr., Unwin, Fteley, Kuichling, and myself and many others, all of whom are in print or otherwise on record to that effect."

To these five names may now be added those of J. T. Fanning and Rudolph Hering, and it will be proper to give the details, in this discussion of a scientific subject addressed to engineers and others interested, of the statement made.

If Hamilton Smith's " Hydraulics " is justly noted for anything, it is so noted for the exceeding care taken by the

author to cull out from a wide range of accessible records of hydraulic experiments all doubtful or inaccurate ones, and to present and use only the best. The Rochester data came quite near being rejected, it is now curious to observe; for on p. 265 of "Hydraulics" we read:

"*Rochester Main.* This experiment appears to be entitled to considerable weight, as the quantity was absolutely measured. It is a pity Mr. Tubbs has not more fully described the methods followed in obtaining his experimental data." But they were allowed to stand, an official report being no doubt considered a sufficient voucher of correctness of statement; and then, again, they were not less than 8% in excess of what all other attainable data testified at the time, and it evidently was assumed that no harm would result from using them merely as confirming, not as increasing, the statements of the other data. So that the conclusions of the work quoted, on the applicability of the coefficients for the discharge of new cast-iron pipe, given on p. 271, to the case in hand, are as follows:

"The given values of this coefficient can, in our judgment, be used with entire safety for computing the flow of reasonably clean water, either through well-made cast-iron pipes, or through riveted sheet-iron or steel pipes, where the rivet-heads do not form quite a notable portion of the area. The pipes must be coated with a varnish of asphaltum and coal-tar, or some other preparation equally good; the joints must be smoothly united, and any curves must be well rounded. These remarks apply to diameters from 1 to 8. For diameters less than 1 the given values of *c* are probably somewhat too high for either cast or riveted pipe; they are

suitable for ordinary lap-welded pipe which has also been coated. . . .

"Also, that the coefficient of roughness or smoothness Δ is a function of D (diameter); that is to say, a degree of roughness which would greatly lower c for small diameters would have but little effect for greater diameters. . . .

"For values of D (diameter) or r larger than those which are given for the same degree of smoothness, c will continually increase with D. For a riveted sheet-iron or steel pipe, with its inner surface properly coated, with D equal 20 and v equal, say, 5, c will probably have the very great value of 180, or perhaps even a higher value. . . .

"The author has had a large experience with riveted sheet-iron pipes in California, and has found no difficulty in protecting them both from rust and the formation of tubercles."

Prof. W. C. Unwin of London is a well-known authority on hydraulics and other branches of knowledge. In 1886 Prof. Unwin had occasion to discuss very carefully all the best experiments on the flow in pipes of different kinds.* He selected all the known experiments which appeared to him to be above suspicion. Using the formula then determined by him, which is of an entirely different form from that used by Hamilton Smith, the discharge of the Rochester conduit would be in the vicinity of 9 million gallons per day. In other words, though developing a formula of different shape, the data used to develop it were practically the same

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*See the article on "Hydromechanics" in the last edition of the Encyclopædia Britannica, and an excellent article on "Formulæ for the Flow of Water in Pipes" in "Industries" Manchester, (1886).

as those used by Hamilton Smith, Jr., and consequently their results are nearly identical.

As the author understands it, neither Hamilton Smith, Jr., nor Prof. Unwin gave great weight to the Rochester results in setting up their coefficients. This was probably due to the Rochester pipe being a compound pipe, both in diameter and in material of construction, and because its reported discharge was in excess, that is, on the safe side.

But had its reported discharge been true in fact, and thus called attention to the smaller discharge of that kind of riveted pipe, it would have necessarily commanded the close attention of these conscientious investigators.

This Rochester conduit had been reported on in April 1889 by J. T. Fanning, M. Am. Soc. C. E., and A. Fteley, M. Am. Soc. C. E., as Consulting Engineers for the city of Rochester.

One of the questions especially put to these gentlemen was: "How much can the present plant be expected to furnish?" Also: "What is the present condition of the conduit and reservoirs, Holly system; and incidentally to the above, have you any suggestions to make as to changes or improvements in the present plant?"

In their answer, and under "Capacity of the Present Conduit," a computation is given in full of the capacity to carry water of the conduit, and its wrought-iron riveted portions are treated exactly as are the cast-iron portions.

As a result, these engineers report: "We have no doubt but that these conduits (the 36 in. and 24 in.) are now delivering approximately 9 million gallons of water daily."

And again, in concluding the whole report, they say:

"The quantity of water which, in our opinion, should be provided to supply the city of Rochester adequately for twenty years, or, say, until 1909, is about 30 million gallons per day. Of this amount, the present plant can be expected to furnish 9 million gallons per day."

Nevertheless, as will have been above noted, this plant was then supplying only somewhat less than 7 million gallons per day, and had probably never carried so much as 8 million. As this may be read without as well as within the United States, it is proper to add that Mr. Fanning is the author of a well-known work on Water-supply Engineering, while Mr. Fteley is the well-known Chief Engineer of the new aqueduct and other important works supplying the city of New York; both gentlemen of high rank as hydraulic engineers.

Mr. Emil Kuichling, M. Am. Soc. C. E., was in 1889 well known as a hydraulic engineer, and succeeding years have added to his technical reputation. All the hydraulic work done in Rochester, N. Y., since 1873 bears the distinct marks of his mind and methods. Those who know the two men, Mr. Kuichling and his chief and predecessor, cannot fail to note Mr. Kuichling's authorship in the technical part of the Rochester report of 1877, for which work credit is also therein given him.

His engagement by the present writer in 1889 has been referred to. In November 1889 Mr. Kuichling copied into a note-book, by request, the calculations he had made in line of the design of the 48-in. riveted conduit then contemplated for the works of the East Jersey Water Company, and this note-book is to-day at hand. The last revise of these computations is dated Dec. 22, 1889. January 29, 1890,

Mr. Kuichling began to use a set of computation-books, making his computations in these books, as is customary in many engineering offices, for the purpose of doing away with the necessity of copying computations for preservation. The last computation is dated Aug. 11, 1890.

In no line or word of any of these books is there so much as a suspicion expressed that the alleged 9¼-million-gallon gauging at Rochester of 1876 was subject to doubt, and throughout them all is a riveted conduit treated precisely like a new, smooth cast-iron pipe. The formula used is that of Lampe: $s = \frac{h}{l} = 0.00039211 \frac{v^{1.802}}{d^{1.25}}$. The result was a pipe 47 in. in diameter, on a slope of 11.8 ft. per mile.

This computation the present writer checked by the use of the table on page 271 of "Hydraulics" by Hamilton Smith, Jr., and the result quoted was changed to a pipe nowhere less than 47¼ inches in diameter, on a slope of 2 per 1000, or 10.56 per mile, which is a trifle more than called for by the Lampe formula; a formula which the Rochester gauging of 1877 was then supposed to have confirmed, established, and even exceeded. The author states it as his distinct and positive recollection that at no time, and in no way, did he ever reduce dimensions of the conduit computed by his colaborer, but to a trifling extent he increased them. With this exhibit before one, it will come as a shock and a surprise, to say the least, that Mr. Kuichling, in a newspaper article of June 13, 1896, referring to a questionable method of computation printed May 2, should say:

"This method was first applied by me early in 1890, before the construction of the Newark conduit was commenced,

but was rejected by the authorities in charge of that work on the ground that no precedent for this method of computation existed, and that the experiments with similar pipes in California did not indicate that the losses would be as great as found by this method.

"From theoretical considerations, however, I was satisfied that some allowance should be made both for numerous alterations in diameter and the projecting rivet-heads of the round seams, and hence when I designed the new Rochester conduit I adopted the principles referred to, in lieu of something better."

It will be observed that the above statement gives as the date for the first application of the described method of computation "early in 1890."

In another place, on February 5, 1896, Mr. Kuichling gives this date: "in spring of 1890."

On p. 341 of the 19th and 20th Annual Reports of the Executive Board of Rochester, N. Y. (to January 1, 1896), we have this statement: "No exact experiments with riveted pipe of such plate thickness and diameter being available at the time (in November 1890), this loss was computed on the basis". . . . then follows the method of computation now under consideration.

On p. 35 of the 1891 Report Mr. Kuichling says: "In the early part of the summer of 1890, about 14½ years after the completion of the conduit, suspicion was first aroused that its delivery was not as large as formerly."

Against these dates the author will set another list of dates, more relevant to a decision as to Mr. Kuichling's responsibility for the method of computation adopted in

1889 and the results found, and indeed conclusive upon the subject.

The last revision of Mr. Kuichling's computation was made Dec. 22, 1889. The contract for 11 million pounds of steel plates for the conduit, which fixed the diameter of the conduit, was closed January 4, 1890, and bids on plate specifications had been invited about Dec. 14.

The author's recollection is distinctly to the effect that he never saw or heard of a shred of that method of computation printed May 2, 1896, before February 6 or 7, 1896.

Why should Mr. Kuichling have made such a computation "early in 1890," or "in the spring of 1890," when it was not until "the early part of the summer of 1890" that "suspicion was first aroused" in the subject-matter?

However, even if he had applied such a method of computation at the dates he gives, it would have come too late to influence the order for steel plates closed January 4, 1890, or to affect the diameter of the conduit. Had he applied the method at any time before January 29, 1890, it would have been his duty to communicate it to the present writer, and to have recorded the method in the book of copied computations, because this book contains both accepted and rejected computations, and was expected to contain all that had been made. As it is, it contains more of the unused than the used, without disparagement to the computer. For instance, the last triumphant conclusion reads: "Hence expansion-joints appear to be necessary"; and pages upon pages are taken up with manifold forms of expansion and other kinds of joints. In one place is committed the common solecism of computing the loss of head through a Venturi meter, as though it

were measured by the loss of head between the up-stream end and the throat—that is, as though it were merely a blunt nozzle—without the expanding down-stream end, which restores the head thus only temporarily converted into velocity, by reconverting velocity into head, and leaves the head at the down-stream end of a Venturi meter nearly the same as at the up-stream end of the meter. Many pages are taken up with computations relating to cast-iron pipe.

Enough has been said to show that no such method was concocted, and communicated to the author, before January 29, 1890, and there is no trace of it in the computation-books used after that date. The probabilities of the case are that this method was thought out after "suspicion was first aroused," "in the early part of the summer of 1890," or later, say "in November 1890"; or that the application stated to have been made in November 1890 was also the *first* application of that method. It was never communicated to, still less rejected in 1889 or prior to July or August 1890 by, "the authorities in charge of that work," or by the present writer; so much is as certain as both documentary testimony and the author's distinct recollection of events can make it.

After July 1890 it was too late to make any changes in the dimensions of the conduit, no matter what results might have been discovered at Rochester, or methods of computation evolved in consequence thereof, or new experiments made. The conduit was then under contract in all its parts.

Was the author justified in classing Mr. Kuichling with a number of able hydraulic engineers, and saying that Mr.

Kuichling had been deceived by the alleged Rochester gauging of 1876, the same as the others?

Apparently Mr. Kuichling would prefer not to be so classed, and yet to have it appear that he had not been thus deceived. Nevertheless he himself says that "suspicion was first aroused . . . in the early part of the summer of 1890." Upon the above facts the matter is left for the deliberate judgment of the reader, and especially of hydraulic engineers.

Although the list of names of engineers first given has already been extended, it may be well to still further increase it. Mr. Rudolph Hering, M. Am. Soc. C. E., needs no introduction to American engineers. As one of the translators and authors of a work dealing especially with the subject of the flow of water in conduits,* he had had, in 1889, especial training on this very subject; but this did not prevent him, in the winter of 1891, during the discussion on Mr. Rafter's paper,† from taking most radical ground in favor of the *smoothness*, hydraulically considered, of large riveted iron pipe. He takes the lead in their favor in the discussion, and calls them 10% to 35% better in carrying capacity than new cast-iron pipes.‡ The carrying capacity of the Rochester conduit, when new, he computes as 8,725,200 U. S. gallons per 24 hours, and then excuses himself for having arrived at so small a result. Says he: "I consider, from the above independent data and above reasoning, the original quantity (9,292,800) most likely to have been correct.'

* Flow of Water in Rivers and Other Channels (New York, John Wiley & Sons, 1889).

† Tr. Am. Soc. C. E., 1892, I, 40.

‡ Tr. Am. Soc. C. E., July 1896, 298.

He has no mercy on poor Mr. Rafter. By the vicissitudes of American municipal politics, Mr. Rafter had just failed of election to the office of Chief Engineer of Water-works of Rochester, N. Y.; it was just then the rage to abuse that gentleman and his professional work: he was being crowded, so to speak, towards the goal of high discharges for all kinds of pipe, and Mr. Hering chose to take a leading position in this detestable craze and game. He sees "no justification in the assertion of Mr. Rafter that by the recent tests considerable doubt is thrown upon the original determination of flow. It is also evident, notwithstanding the sentiment expressed in the last sentence of his paper, that the modern views as to the value of *c* have in the Rochester case rather been substantiated than otherwise."

Will it be believed that this same disputant within the short space of five years could turn about and be equally zealous to join or lead another such body of men, inflamed by the passions of the hour, in the sport of attempting to crowd another member of the profession towards the other goal, that is, in a diametrically opposite direction? Yes, this also was done, and Tr. Am. Soc. C. E., July, 1896, p. 280, demonstrates how nothing in the way of pipes can compare in hydraulic *roughness* with riveted pipe, and that this had been known for a very long time, and should have been heeded in the practice of all, prior to 1889, to say the least. Of course this note, which is considering the computation of a riveted conduit in 1889, must appeal from the discussion of 1895 to that of 1891, disputants remaining the same; and appealing thus, we class Mr. Hering among the noted engineers who in 1889, and even as late as 1891, considered

riveted pipe constituted to carry as much and more water than new cast-iron pipe, other things being equal. He too had been deceived by the Rochester alleged gauging of 1876.

Thus have been cited in support of the propriety in 1889 of computing a large riveted conduit as though it offered no greater obstruction to the flow of water than new cast-iron pipe, Hamilton Smith, Jr., Prof. Unwin, A. Fteley, J. T. Fanning, Emil Kuichling, and Rudolph Hering; an array of engineering talent which both argues and demonstrates the state of the art of computing the carrying capacity of riveted conduits as it was from 1877 to 1890 or 1891.

NOTE C.

MEASURING WATER.

A lecture delivered January 25, 1895, before the students of the Rensselaer Polytechnic Institute, Troy, N. Y.

The subject which I have selected for this discourse may be called "Measuring Water," or, to particularize, the measurement of a *stream* of water; being the determination of the cubic volume of water that thus passes a given point in the adopted unit of time. For most purposes the unit of volume, when using English measures, has been agreed upon in favor of the cubic foot, and the nations of the earth, being fortunately agreed upon their measures of time, have settled upon one second of time as the unit to use in measuring water. Nevertheless, the million United States gallons in twenty-four hours has become a standard for city water-supply practice in the United States, and an acre in area covered an inch, or a foot, deep in a month, or in a year, is used in irrigation practice. But I would warn all

engineers to be very slow to add to the number of such standards of measure for flowing water, and to abstain from and frown down such absurd standards as cubic yards per day, or tons weight of water per day, or even cubic feet per minute (instead of second), and other incongruities found mainly in the writings of British engineers. As exercises in the art of arithmetic for children such computations may have value, but in the work of civil engineers they become a stumbling-block to an advance of knowledge, and, while unduly magnifying the unessentials, they indicate a deplorable lack of appreciation of the essentials of the art of the civil engineer.

Cubic measures do well enough for the contents of vessels, or, as we may express it, for dealing with the science of hydrostatics. But so soon as the water to be measured is in motion, or so soon as the science of hydraulics has been entered upon, we must get clearly in our minds the idea of rates of flow, or of a procession of such cubic volumes passing a given point in a certain unit of time, as of a flow of so many cubic feet per second.

No such idea appears to have formed part of the stock in trade of the ablest engineers in ancient times, or at the beginning of the Christian era, nor probably for some 1500 years later. Thus Frontinus, perhaps the earliest writer on practical hydraulics that we have, has barely a conception of the fact that some streams of water flow faster than others, but his measurements of any and of all streams is based solely upon the areas of their cross-sections. You can readily see how imperfect is such a conception of the volume of a flowing stream; though we must admit that to this day many a man

yet struggles with the similar crudities of "the amount of water that will fill a 6-inch pipe," or of so many "square feet of water" let onto a water-wheel and the like; when, as has been said, he might as well attempt to define the volume of a cylinder, or of a parallelopipedon by giving only the area of its base.

A stream of water, then, is defined by stating what it will produce in a unit of time; usually the cubic feet it will produce in one second of time. And this definition could not become current even among experts until considerable attention had been paid to measuring the velocity of running water. These measurements, again, had their origin in the search for the numerical values of velocities of efflux through orifices and out of vessels of water; in the establishment of the equation known to all of you, the fundamental equation of the whole modern science of hydraulics: $v = \sqrt{2gh}$.

You may know that this equation was first published in 1732 by John Bernouilli of Basle, Switzerland, though his son Daniel Bernouilli was credited by his father with having furnished an independent proof of the same relation between head and velocity of efflux, at the time, and in 1738 the son published his own celebrated "Hydrodynamica." But these two founders of the modern science of hydraulics had been preceded by, and had had the benefit of, the labors of many generations of earnest workers in the applied sciences. If I may be allowed to quote from myself, I give you on this point an extract from my lecture on "Frontinus and his II. Books on the Water Supply of the City of Rome, A.D. 97," published in the 1894 number of the Journal of the Association of Civil Engineers of Cornell University: "We who

have been educated in English-speaking countries have been accustomed to consider Lord Francis Bacon (1561–1626) as the author and apostle of the experimental method of studying science. But modern research shows him to be entitled to the latter credit only as he influenced his countrymen of Great Britain, and he himself made no experiments of any note. For a hundred years before his time lived that remarkable painter, sculptor, teacher, and engineer, Leonardo da Vinci (1452–1519), the misfortune of whose fame it has been that his voluminous works, hidden away for centuries in private keeping and exposed to manifold vicissitudes, found no publisher until the last few years; and have, even to-day, not been before the public long enough to be used by modern writers as they undoubtedly will be. He not only preached the duty of study by means of experiment, but was himself a most prolific experimenter and a teacher. In the last-named way he anticipates Lord Bacon; in the other he is the forerunner even of Galileo." "His experiment on the law of falling bodies is most interesting in connection with the matter we are now considering. He used two long boards hinged together like the leaves of a book. On the inside these boards were smeared with tar or wax. A string-latch served to suddenly close them. He then takes a small tube filled with shot, the tube having nearly the same diameter as the shot. This tube is held vertically in and over the angle of the wooden book, itself set up vertically. The shot are then allowed to drop out, and on pulling the latch are caught, as they fall, between the leaves of the wooden book, and their relative distances, as they are falling, are impressed on the tar or wax covering of the boards.

"Until quite recently Galileo has been supposed to have been the first experimenter on the laws of falling bodies, but here was this great engineer and teacher busily at work at it 100 years previously. However, with Galileo (1564–1642) we first touch the modern science of 'dynamics,' or of bodies in motion. Says Rühlman: 'For the proper founding of the science of dynamics, or of the science which treats of the causes and the laws of motion, were requisite talents of a degree of eminence such as the Lord Almighty called into being with Galileo in the year 1564.' But Galileo had no proper means for measuring time, no clocks or watches. Both he and his son tried to make a clock, but did not succeed. Instead he used a large bowl of water, having a small orifice at the bottom, and compared times by the weights of water discharged during these times, using his finger to start and stop the flow of water out of the bowl. As we shall see, it is a reasonable assumption that this makeshift of a clock became, in the hands of Galileo's pupils, and of those of his pupil's pupil, the suggestion for an experimental demonstration of the laws of efflux in general.

"Castelli (1577–1644), the pupil of Galileo, was a Benedictine monk, from that same Monte Cassino which saved Frontinus' commentary to posterity, and he first showed that the quantity of efflux, in a given time, depended by law on, or was a function of, the depth of water in a bowl, such as the one just spoken of; that is, was a function of the head. But he wrongly stated this law, making the quantity vary directly as the head. It was his pupil, Torricelli (1608–1647), the inventor of the barometer, the grandson, in a professional sense, of Galileo, who first proved, in 1644, or only two

years after Galileo's death, that the velocities of efflux are as the square roots of the head. But this still furnished no numerical value for the velocity of efflux. Still other and yet other great men had to devote their lives to this cause. Thirty more years had to pass by, till Huygens (1629–1695), the inventor of pendulum clocks, first found the numerical value of the acceleration of gravity, commonly represented by the letter g in 1673, and sixty-five more years had to elapse, until the genius of the two Bernouillis, father and son, in 1738, or 250 years after Leonardo da Vinci, finally laid the foundation of modern terminate hydraulics by writing the equation of $v = \sqrt{2gh}$, every letter and character of which may be considered the contribution of and a tribute to the skill and perseverance of one or more of the many great men I have named. v may stand to symbolize the experiments of da Vinci and of Galileo; $2g$ alone would suffice to immortalize Huygens, were he not already permanently distinguished by his invention of pendulum clocks and other works; h may serve to recall Castelli; and the square root sign, his pupil, Torricelli: and when next we write the formula, let us remember that it took 250 years of work, not to speak of another and a preceding 250 years or more of speculation, to put it upon the blackboard of the world. But no amount of speculation alone, or of peripatetic philosophy, would have produced it. To do that, the work of centuries of earnest men, not too proud to dip their hands into bowls of water, and to *experiment* in hydraulics, the while they were wearing mechanics' overalls, so to speak, was absolutely necessary."

Men of this stamp have followed, since 1738, in rapid

succession, and were hydraulic observatories endowed with but a small portion of the wealth that has been devoted to furthering astronomical recreations, very much more such work would have been done up to the present time. Indeed it is sad to consider how much has been as yet withheld or lost to the world for the want of endowed hydraulic observatories. It was Galileo who more than 200 years ago deplored this state of affairs, and declared that, strangely enough, he could learn more of the movements of Jupiter's satellites than he could of a stream of water on the earth which he inhabited.

But working in the best way they could, the practical part of the science of hydraulics, and the art of measuring water, have been developed since 1738 by many earnest workers in this field, some of whom I will name in the order of their birth:

Michelotti, the elder	1710 to 1777
Brindley	1716 to 1772
Chézy	1718 to 1789
Smeaton	1724 to 1792
Bossut	1730 to 1814
Du Buat	1732 to 1787
Borda	1733 to 1799
Venturi	1746 to 1822
Prony	1755 to 1839
Woltmann	1757 to 1837
Michelotti, the younger	1764 to 1846
Eytelwein	1764 to 1849
D'Aubuisson	1769 to 1841
Thomas Young	1773 to 1829
Bidone	1781 to 1839

Poncelet	1788 to 1868
Lesbros........................	1788 to 1867
Darcy..........................	1803 to 1858
Weisbach.......................	1806 to 1871
Francis........................	1815 to 1892

and by Boileau, Bazin, Borneman, and a host of others still living, as well as many, such as Pitot, Cabeo, and others, of the years prior to 1738. These are the men to whom we owe the present state of the art. It is true that much that they have done has become nigh useless in the practical pursuit of measuring water; but all science, all knowledge is thus developed with the accompaniment of a great waste of energies, somewhat as the operations of nature include a waste of labor and of benign possibilities. Thus the multitude of experiments on efflux from vessels and through orifices can find but little use in practice. The intent seems to have been to so study efflux as to deduce its laws up to the point of being able to meter water from a knowledge of the size and shape of the orifice and the head acting upon it. Speaking from the standpoint of the practician, this has not been accomplished, nor is there any present outlook that it ever will be accomplished. Each shape, each minute variation of shape, each accompanying circumstance of efflux, varies the coefficient of discharge; so that the most that can ever be affirmed is that a precise reproduction of an orifice that has been experimented on and a reproduction of the attending conditions will reproduce the experimental discharges. This is the sum total of our knowledge even in a case apparently so simple as that of water wasting over a

weir. I say apparently so simple, because, as long known, the latest experiments of Bazin have clearly shown the multiplicity of forms according to which water may proceed to spill over a weir.

Returning to the case of discharge from an orifice, we have here probably the earliest method devised for measuring water. Frontinus, who wrote A.D. 97, describes how water was metered to the Roman water-takers. It was led from the aqueducts to a group of cisterns set up near the places of final consumption of the water, and into the walls of these cisterns were inserted bronze, circular, ajutages, about nine inches long, of the desired diameter, stamped with their size and the name of the water-works superintendent who had set them. Two specimens of these ajutages have survived the wrack and ruin of the centuries and are preserved in two of the Roman museums. Frontinus knew that these ajutages must all be set on the same elevation, that is, as we would now say, under equal heads, to cause them to discharge equal volumes; but to show you how crude were his ideas, and those of the most learned of his contemporaries on these subjects, I quote what he says about it: "In setting ajutages care must be taken to set them on a level, and not place the one higher up and the other lower down. The lower one will swallow up more; the higher one will suck in less, because the current of water is drawn in by the lower one." (Frontinus, 113.)

Frontinus also knew that the ajutages must be set with their axes at right angles to the trend of the current, and that they would discharge more and less than the ajutage set at right angles, if set inclining with or against the current;

finally, he knew that a large pipe attached to the down-stream end of the ajutage would carry more water than a pipe of the same diameter as the ajutage, attached in the same manner; and a law of ancient Rome prescribed that the diameter of the attached pipe must be the same as that of the ajutage, for a distance of 50 feet down-stream from it. But with these precautions Frontinus apparently exhausted his means of measuring water, and the resources of his time, to the end that the measurements should be consistent among themselves. His unit was the discharge of such an ajutage 5/4 of a digit (about 0.907 inch English) in diameter; which he calls a quinarium, or, as we would say, a "fiver." For an ajutage of double this area the discharge becomes two quinaria, by reason of such double area; and so on, even up to the measurement, by a cross-sectional area of the stream flowing in an aqueduct, of the discharge of that aqueduct.

Of course work like this can represent only an embryonic state of the art of measuring water. But it endured for yet 1543 years, until Castelli, the pupil of Galileo, saw that more water was discharged out of a hole in the bottom of his water-clock bowl when the bowl had much water in it than it did when the bowl was nigh empty, and published his ideas about it, as we have seen, in 1640.

From this time on, especially after the proof by Torricelli, only four years later, in 1644, that the discharge varied as the square roots of the head of water on the orifice, the importance of the head of water became firmly established. Frontinus had said that ajutages should all be on a level, but it is not known at what level he set them. Old orifices for

regulating and limiting, not measuring water, used for irrigation purposes in the fourteenth and fifteenth centuries in Italy, had the ordinary water-level even with the top of the rectangular orifice. In 1764 the legal *measure* of water used for irrigation was established in Modena, as the amount flowing out of a defined rectangular orifice under a defined head, and this is one of the earliest recorded uses of a fixed head on an orifice to define a measure of water in irrigation practice.

Long before this, however, it had become customary among the workmen that had charge of the public fountains of Rome and of Paris to measure volumes of water by the discharge through a circular orifice in a thin vertical plate; the unit in Paris, for example, being the discharge through an orifice one Paris inch in diameter. Belidor, who wrote in 1737, says (Archit. Hydr., II, 366) that the "fountainiers" were not particular what head was acting on the orifice so long as it was a moderate one. Their subdivisions of the water-inch were also entirely irrational and erroneous. The first one who attempted to determine the meaning of a water-inch in fixed measures was Mariotte, who lived 1620–1684, and who found the discharge of a Paris water-inch, when the head on the upper edge of the orifice was 1 "ligne," about 1/12 of an inch, to be about 14 "pintes" per minute, equal to about 0.47 cubic foot per minute. The Paris inch was about 6% larger than the English inch; and with Gallic perversity the Paris "pinte" differed less than 1% from the U. S. quart.

Belidor notes some of the many objections to this mode of expressing a definite measure of flowing water, and strove

to improve upon it by substituting rectangular orifices of uniform height, set on a level, but having varying widths, for the circular orifices of varying diameter used in his time, whose centres or bottom edges were all on a level. The method is, however, necessarily beset with so many chances for error that it never can succeed for work that aims at the merest rudiments of exactitude. Again and again in the world's history has it been attempted to introduce it, in every case by uneducated men, or in crude forms of society, only to reveal its manifold imperfections and to vex and encumber the contracts and legislation of succeeding several generations before it could be got rid of. The miner's inch, gradually disappearing in our Pacific states in favor of the cubic foot per second, is one of the latest examples of the statement just made.*

The reason for this is readily seen when the multitude of dimensions and forms of the measuring apparatus, each one of which has an influence on the discharge produced, are taken into consideration. Whether the orifice be cut out of a plate 1/16 inch thick or 1/32 inch thick, or through an inch board or a half-inch board; whether the bottom of the vessel be 1 inch or 3 inches below the bottom of the orifice, whether the orifice be filed off smooth or left as cut, whether the holes be punched 2 inches apart or 3 inches apart, and a multitude of other such circumstances, all affect the resultant discharge. The one thing to do with such a crude unit of

* See a Report to the Montana Society of Civil Engineers by Prof. A. M. Ryon, 1894. Also Journal of the Association of Engineering Societies, January 1895.

measure for flowing water is to get rid of it, and this is happily being accomplished in the course of time.*

Starting with the Roman attempt to measure flowing

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* So long ago as the middle of the fifteenth century there was at least one man who saw the defects of an orifice of discharge, as a unit of measure, very clearly.

In Leonardo da Vinci's Manuscript F (Venturi, Essai sur les Ouvrages, etc., Leonardo da Vinci, 1797, p. 20) may be found the following :

CONCERNING THE WATER THAT MAY BE DRAWN FROM A CANAL.

The quantity of water that discharges from a canal through an orifice of a given size may vary on account of many reasons :

1. By reason of the height, more or less great, that the surface of the water of the canal is over the opening.

2. By reason of the more or less velocity with which the water of the canal passes along the bank in which is placed the opening.

3. By reason of the sides of the opening being more or less convergent.

4. By reason of the thickness of the frame of the orifice being greater or less.

5. By reason of the shape of the opening being circular, or square, or triangular, or lengthened out.

6. By reason of the axis of the opening being more or less inclined to the direction of the bank of the canal.

7. By reason of its being more or less inclined to the horizon.

8. By reason of the opening being placed on a convex bank or on a concave one.

9. By reason of protuberances or depressions in the bed of the canal, opposite to the opening.

10. By reason of the air intermingling or not intermingling with the current of water that discharges from the opening.

11. By reason of the water discharging from the opening freely into the air, or discharging through an open conduit, or through a closed pipe.

12. By reason of this conduit having a cross-section greater or less than the orifice of discharge.

13. According as this conduit is of greater or less length.

14. According as the interior of the conduit is smooth or rough, straight or curved.

When it is considered that this was written before the invention of printing, and before Columbus discovered America, it becomes a marvellous exhibit of a thorough and searching analysis made merely by force of genius and without aid from the teachings of hydraulic science, then as yet unborn.

water merely by the cross-sectional area of the stream, thence passing to the mediæval way of measuring it by the number of streams one inch in diameter, under some small head, which it would produce, thence reaching the point where these small streams were defined to act under a given head, so as to regulate the affecting circumstance of discharge of greatest importance, we have at last arrived at the modern method of defining flowing water in cubic measure per unit of time, or at the definition of cubic feet per second.

I will ask you now to distinguish between mere computations that indicate the discharge from orifices, through pipes, or in channels, from instruments and methods by which such streams are directly examined and measured. The last process alone we will call measuring water. It may also not be superfluous to ask you to distinguish between forms of apparatus that may be set to discharge uniformly certain given quantities, so-called module, as likewise not included in the instruments and methods to be used for effecting a measurement of a given stream; nor to ordinary water-meters, which measure volumes, but do not measure rates of flow. But I shall include in such instruments the weir, which may be reproduced in the precise form used to establish a given weir formula, so readily, that it has won a place for itself among water-measuring instruments, something that the orifices or pipes that have been named are not likely ever to accomplish.

But a weir measurement is only a reasoning by analogy from the recorded results of measurements made over a like weir into some measuring-tank, so that at the foundation of weir measurements, and at the same time as the simplest of

all methods of measuring water, we have the measuring-tank, or, as we may call it, the grocer's pint or quart measure. But when conducted with accuracy, measuring water by means of a measuring-tank is an art, to be learnt like any other, some features of which may now be illustrated.

Tank volumes may be measured in two ways: either directly, by cubic contents, or indirectly, by first weighing the quantity contained, and then computing the cubic contents from the temperature of the contained water and from its weight per cubic foot.

If the first method be followed, the tank must be built on purpose for it, extraordinarily strong and stanch, so as not to change in shape when filled with water, and by no means to leak. If of wood, the wood must be waterlogged. Levels of water must be measured with a hook-gauge to thousandths and to ten-thousandths of a foot. The form of the measuring-tank must be a regular one, all the corners straight, sides without warp, and all linear measurements must be determined with extreme accuracy. You can readily see that it is easier to use a tank or vessel of most any make and form and to weigh the contained water.

To limit the lengths of time during which the stream whose flow it is desired to measure discharges into the tank, the best way is to use a movable spout between the stream of water and the tank. A carefully tested stop-watch, and an assistant to cause the spout to discharge the water on a given signal into the tank and again to one side of it, will determine the length of time during which the tank received the discharge to be measured within the fraction of a second. Large movable spouts of this sort, to control discharges of

considerable volume, may be found described in Francis' Lowell Hydraulic Experiments, and in the description of the experiments made with the Venturi meter in the 1887 volume of the Transactions of the American Society of Civil Engineers.

Such measuring-tanks are the very simplest forms of water-measuring apparatus, so simple that they are not thought of many a time by the hydraulic engineer, whose head may be filled with the pages upon pages treating of the cases and the coefficients of discharge given in the text-books, but duplicates of any one of which cases are so seldom met with in practice. Whenever a small stream of water is to be measured, one's first thought should always be the tank, the pint measure. When that is not applicable it will be time enough to turn to other methods.

One such other method, we have agreed, shall be the weir. Now a weir may be looked upon in two ways: as a hydraulic study of the discharge of water over it, and, again, strictly as a method for measuring water. If the first view be taken into consideration, the last word has by no means yet been said upon the subject, and the latest may always be the best. But if the second-named object be kept in mind, we have in Francis' Lowell Hydraulic Experiments nearly all that will ever be needed upon that subject. For the weir experiments recorded in that classic of hydraulic literature embrace all the cases of weir measurements that are ordinarily met with in practice. We have but to reproduce the conditions of those experiments to have the results at once known with the same degree of accuracy that distinguished the tank measurements recorded in this book. As is well known, no expense was

spared in the conduct of the Lowell experiments to insure extreme accuracy, and as a consequence the boon of exact knowledge on the cases of weir discharge treated in the book named has been conferred, by these experiments, on succeeding generations.

Another useful method of measuring water applicable, however, when accuracy is desired, only in rectangular channels and for the cases of a uniform flow during the hour or more required for the measurement, is presented by the use of floating tubes. This method is a very old one, having been first used by Cabeo, an Italian professor, in 1646, but the method was first accurately tested, and established as a trustworthy method of measuring water, by Mr. Francis, as related in the book that has been named, in Lowell Hydraulic Experiments. This was done by measuring the same streams of water at one and the same time, both over a weir and by means of floating tubes. It will not be in the power of man, presumably, for many years to add profitably to what is said on this method of measuring water in the book that has been referred to.

We now come to two instruments that enable us to determine the velocity at any *point* throughout the cross-section of a stream of water. I allude to the current-meter, or moulinet, or Woltmann wheel, and to Pitot's tube.

For small streams of water, for jets, or in the interior of pipes, the latter instrument alone is applicable for a close investigation of the distribution of the velocities of the water in the cross-section of the stream. In large canals and rivers the current-meter becomes not only the superior instrument, but almost the only practicable one. Many instruments

have been invented for the same purpose, or were invented in the early days of hydraulic science, but are of no more practical interest now than would be an examination of the bones of extinct animals.

Woltmann, the inventor of Woltmann's wheel, was a hydraulic engineer employed by the city of Hamburg, who lived from 1757 to 1837, and got his idea of the current-meter from an anemometer in use in his day. Since then the instrument has been constructed in a great number of ways. At first it had to be taken from the water after each time of running some definite period of observation to get the reading. Latterly, electrical or phonetic connection is made between the meter under water and some form of counter above water, so that observations may be made continuously. The form of wheel, also, has changed many times. Care should be taken that the wheel be as little liable to change of form as possible, and that all parts, such as bearings that produce frictional resistance, be as constant in condition as possible. All this, so that when once rated the instrument may not be subject to a change of rate. It is not exactly correct to assume that the method of rating usually pursued, that of dragging the meter through still water at known velocities, is mathematically equivalent to letting the water, moving at an average velocity equal to these same velocities, impinge upon the meter held still. Preliminary reasoning would so indicate, it is true, but a closer examination reveals differences, and in hydraulics reasoning alone will never indicate the weight to be given to objections or to analogies. To do this, resource must always be had to the results of careful experiments.

A valuable attribute of the current-meter is the fact that

it can be used to measure the *average* velocity in a vertical, or in a horizontal, or in a whole cross-section, by slowly moving the meter over these lines or areas and exposing it to the current for equal lengths of time over equal spaces or areas. Some excellent work of thus integrating the velocity in the cross-section of a stream and other results of experiments with the current-meter may be found described in an article by F. P. Stearns, M. Am. Soc. C. E., in the Transactions of that Society for August 1883; and the reports of the Corps of Engineers, U. S. A., contain many examples of the use of the current-meter on the rivers of the United States. See also *Engineering News* of January 10, 1895. In Europe, also, in Germany and France, much work has been done with it.

The modern use of the Pitot tube may be likened to that of a microscope in hydraulic investigations when compared with that of the current-meter. It is a very old form of current-measuring apparatus, Pitot having lived from 1695 to 1771, but the instrument has received many improvements at the hands of Darcy and Bazin, and of many others. The point of a Cross stylographic pen, with the central wire removed, has been a favorite form of the tube which is directed against the current to be measured, and this characteristic feature will give an idea of the delicate work this instrument is capable of. Some excellent investigations of this sort are described in the Transactions of the American Society of Civil Engineers for November 1889, page 411, in a paper on Fire Streams by John R. Freeman, M. Am. Soc. C. E.

Another method of measuring water is by means of the

Venturi meter, which has further been converted by the attachment of a suitable register into an ordinary dial meter, like the house meters commonly met with. There being hardly a limit at which the size of the stream to be metered by this meter becomes too large for it, and as the register is essentially the same for small meters and for the largest sizes, we could with the Venturi meter register on a train of dials the daily consumption of the present or of the Greater New York, or of London, or of the two combined, as easily as that cf a 1/2-inch stream. As a matter of fact, this meter has already measured the flow of water through a 9-foot tube up to over 245 cubic feet per second, about 160,000,000 gallons per 24 hours. It has also been tested on a 1/4-inch stream, and meters the one as readily as it does the other. Nor is it affected by or does it materially affect the pressure of water at either the intake or the delivery end; that is to say, it can be used on pipes under any pressure and destroys very little of the head or pressure for purposes of passing the water through the meter. For instance, it need never thus destroy more than a foot of head when passing maximum quantities. A 48-inch meter in use on the works of the East Jersey Water Company, for example, loses four inches of head to meter 25,000,000 gallons per day. And by the use of by-passes, any loss of head need obtain only during the period of measuring water.

These are some of the general characteristics of the instrument, which may now be described more in detail, the more so because its description has not yet been placed in text-books generally, although Merriman's Hydraulics contains a good discussion of it.

The instrument consists of a converging, followed by a gently diverging, tube; between the two is a short cylindrical piece, surrounded by a pressure-chamber which is connected with the interior by piezometer-holes. (See Fig. 1.)

FIG. 1.—VENTURI METER.

A similar pressure-chamber surrounds the main pipe at the inlet end, and may also be applied to the main pipe at the outlet end, if it be desired to measure the loss of head in passing the meter.

Now it is a fundamental principle in hydraulics that the hydraulic pressure of the water against the interior of a pipe containing water in motion is equal to the hydrostatic head (to what the pressure would be if the water stood still) less the head due this contained velocity.

Or if P be the pressure in the terms of the height of a water-column at the inlet,

P_1 be the pressure in the terms of the height of a water-column at the throat,

$v =$ the velocity at the inlet,

$v_1 =$ the velocity at the throat,

$P_s =$ the static pressure; then

$$P = P_s - \frac{v^2}{2g} \quad \text{and} \quad P_1 = P_s - \frac{v_1^2}{2g}.$$

Ordinarily the throat is made 1/3 the diameter of the main pipe, or its area = 1/9 of the main pipe area, and therefore

$$v_1 = 9v \quad \text{and} \quad P - P_1 = \frac{v_1^2}{2g} - \frac{v^2}{2g} = \frac{80}{81}\frac{v_1^2}{2g}.$$

But $$P - P_1 = H_v.$$

$$\therefore v_1 = \sqrt{\frac{81}{80}}\sqrt{2gH_v} = 1.0062\sqrt{2gH_v}.$$

Experiments show that in fact for three different meters tested, of 1 foot, 4 feet, and 9 feet, diameter of main pipe, and within the limits of velocity ordinarily met with, the coefficient to be used with this formula varies with the velocity through the three meters only from .972 to .997, which is important as fixing the discharge of any such meter without making experiments with it. After such a meter has been rated its discharge is exceedingly uniform and can be relied upon as correct within a small fraction of 1% for any single reading.

As the indications necessary for the measurement of the water passing through a Venturi meter are merely the pressures in two little pipes, these same two pressure-pipes may be used to operate several mechanisms without interfering with each other, which would not be true if, for instance, the pressure-pipes conveyed a *stream* of water, instead of only static pressures. Thus a diagram can be drawn by them that will indicate the *rate* of flow through the meter for any convenient length of time. This makes the meter a so-called waste-water meter, used to find and to locate leaky house-fixtures in cities. But the same pressure-pipes can be

used to operate the ordinary form of register (see Fig. 2), thus metering the water as in the common forms of dial meters. And they can also show their contained pressures directly in glass tubes, or on Bourdon, or on mercury pressure-gauges, affording the means of testing the several instruments by computed results.

I have come to the point of being ready to set the tubes of these meters at selected locations throughout the distribution system of cities, so as to be able to meter the consumption of any *one* or more of its several districts at any desired time. The loss of head occasioned is so small, no more than is caused by a square turn, or branch, and not so much as is caused by a check-valve, that no by-passes need be set. Whenever desired, a dial register, or a waste-water indicator, can be set up at any convenient place, 1000 feet, if need be, from the tube, and connected with it permanently or temporarily. Of course every system of water-works should have a Venturi meter on its main pipe or conduit, just as every gas-works has a master meter to measure its total output of gas.

If set in the penstocks leading to turbines, or in the tail-races of mills as ordinarily situated, one or more by-passes can be provided in very particular cases, if desired, which can remain open when the meter is not in use, to avoid the few inches' loss of head occasioned by the meter when it is in action, unless, indeed, the situation is such that a few inches' loss of head can be compensated for, or such that they are of no consequence.

When set in an open channel the case becomes somewhat peculiar. The pressure at the throat is then a negative one, or is measured by the amount of suction, or of " vacuum,"

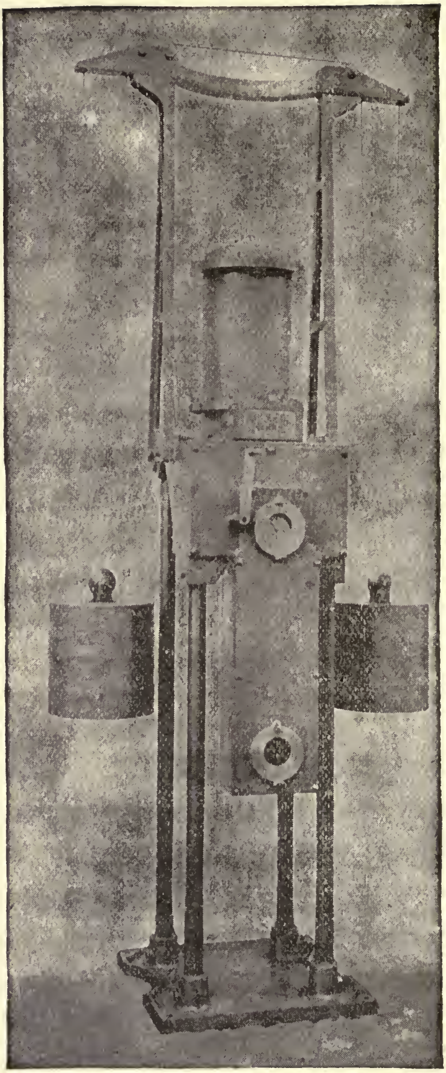

FIG. 2.—REGISTER OF THE VENTURI METER.

it will produce. But the *difference* of pressure between the same two pressure-pipes governs the indications of the meter as before, and the total loss of head is much less than if a weir had been used. In this form, anu built of wood, the Venturi meter is destined, in my belief, to do important work in irrigation practice. Also in the measurement of sewage, in which case the meter-tube can be built of brick, and with the invert grade-line undisturbed, by placing the throat-area eccentrically to the area of the main sewer.

Making full use of "new-fangled notions" is peculiarly the province of the rising generation; and I look confidently to the hydraulic engineers among my hearers to profit by the fact that a meter which can be set in a pipe of any diameter, and of the simple construction that has been shown you, can now be put to use in their practice.

NOTE D.

Investigation of the personality of the originator of the Chézy formula reveals the pathetic history of a human life. The original sources of information are:

Biographie Universelle, vol. V., A. de Chézy.

Le Sage, P. C., Notice de Perronet. 1805.

Prony, Notice de Perronet. *Comptes Rendus* of April 29, 1829.

Biography of A. L. de Chézy (son of A. de Chézy)—a distinguished philologist, and one of the first to study Sanskrit, who died in 1832—by his widow.

See also:

Tarbé de St. Hardouin, Notices Biographiques, etc. Paris, 1884.

From these it appears that Antoine de Chézy was born 1718, at Châlons-sur-Marne, and died at Paris, as director of the École des Ponts et Chaussées, in 1798, having held the office less than a year. The city hall of Châlons contains his bust, by Houdon, and his portrait is in the École des Ponts et Chaussées. All accounts agree that his modesty went to extremes. He wrote many valuable papers, but published only one, on the Plumb-line and on Levelling Instruments, printed in the 1768 volume of "Mémoires presentés par divers Savants Étrangers"; translated in *Nicholson's Journal*, 1800. He is reputed to have been the inventor of the engineer's spirit-level. His essay demonstrates that exactitude cannot be attained by using plumb-lines, be they as fine as practicability will admit of, and he then describes the proper construction of spirit-level tubes, etc.

As assistant to his father-in-law Perronet, he took part in many celebrated works, such as the Neuilly Bridge, Canal de Bourgogne, Canal de l'Yvette, etc., but was content to efface himself in all accounts of those works. His manuscript report, of 1775, on the Canal de l'Yvette, said to contain the original Chézy formula, is addressed to Perronet, and is reported to be in the library of the École des Ponts et Chaussées. He had been appointed by the government to report on this work in 1769 with Perronet. Perronet mentions Chézy in a mémoire on the Canal de l'Yvette, read at the Académie Royale des Sciences, Nov. 15, 1775, but gives no account of Chézy's part of the work done. Le Sage, and Prony in 1804 in a meeting of the Institute, and again in his Eulogy of Perronet, in 1829, go out of their way to praise Chézy. Perhaps the explanation or the cause of all this is written when it is

stated " il mourut pauvre "; he died poor. For six months work on the Canal de Bourgogne, inclusive of the making of " a mass of reports," he received 129 francs, less than $26.00. It must be admitted that this is small pay, even in France, and in the middle of the eighteenth century, especially if, as is possible, he had to " eat himself " out of that, such as it was. Living on a small government pension, as a retired engineer of the Ponts et Chaussées, at the outbreak of the French Revolution, thereafter paid in worthless paper-money, he found himself obliged to " sell the horse-hair out of his mattress " to buy food, in 1795, at the age of 78. Shortly after, in 1797, a member of the Directory, Letourneur, was induced to give him the directorship of the École des Ponts et Chaussées, which had certainly been his due three years before, at Perronet's death, if not before. Chézy himself died some ten months later, Oct. 5, 1798.

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